



# PANAMETRICS

221 Crescent Street • Waltham, Massachusetts 02154 • (617) 899-2719

FINAL REPORT

NAS8-26931

**ORIGINAL CONTAINS  
COLOR ILLUSTRATIONS**

PROTOTYPE ULTRASONIC INSTRUMENT  
FOR  
QUANTITATIVE TESTING

By

Lawrence C. Lynnworth, John L. DuBois and Paul R. Kranz

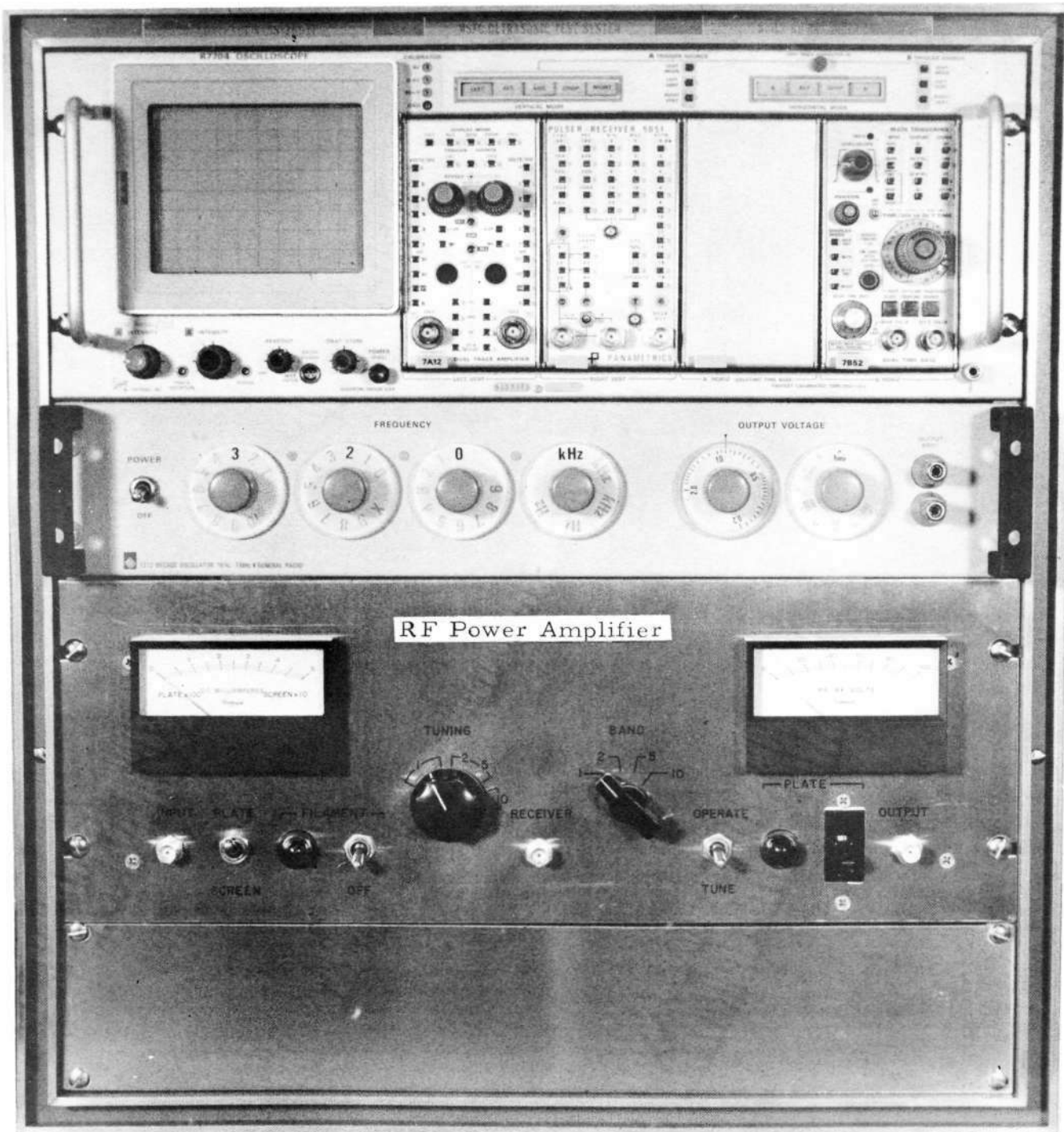
Prepared  
for

George C. Marshall Space Flight Center  
Marshall Space Flight Center, Alabama 35812

Covering the Period April 1971 to June 1972    Date of Publication: June 1972

## ABSTRACT

A prototype ultrasonic instrument has been designed and developed for quantitative testing. The complete delivered instrument consists of a special pulser/receiver which plugs into a standard oscilloscope, a special rf power amplifier, a standard decade oscillator, and a set of broadband transducers for typical use at 1, 2, 5 and 10 MHz. The system provides for its own calibration, and on the oscilloscope, presents a quantitative (digital) indication of time base and sensitivity scale factors and some measurement data. Performance includes a velocimetry capability of better than 0.1%.



Frontispiece. The MSFC Ultrasonic Test System built by Panametrics under Contract NAS8-26931 consists of a Tektronix R7704 Oscilloscope with 7A12, 7B52, Pulser/Receiver 5051 and spare plug-in, a General Radio 1312 Decade Oscillator, an RF Power Amplifier, and a spare panel for special functions.

## TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	1
OBJECTIVE	1
PHASE I	2
PHASE II	2
PHASE III	5
PHASE IV	5
SPECIFICATIONS FOR PULSER/RECEIVER 5051	6
SPECIFICATIONS FOR RF POWER AMPLIFIER	8
RECOMMENDATIONS	9
ILLUSTRATIONS	11
APPENDIX A: VELOCITY MEASUREMENT	A1
APPENDIX B: ATTENUATION MEASUREMENT	B1
APPENDIX C: CABLE EFFECTS	C1
APPENDIX D: TRANSITION TIMES	D1
APPENDIX E: THREE-CHANNEL SIGNAL PROCESSOR DESIGN	E1
APPENDIX F: BROADBAND TRANSDUCERS	F1
APPENDIX G: INSTRUCTION MANUAL FOR PULSER/ RECEIVER 5051	G1
APPENDIX H: INSTRUCTION MANUAL FOR RF POWER AMPLIFIER	H1
APPENDIX I: DATA SHEETS ON TEKTRONIX R7704, 7A12, 7B52 AND GENERAL RADIO 1312	I1

## INTRODUCTION

An ultrasonic test system may be analyzed in terms of factors such as electronics, the transducers, the coupling means, the specimen, and possibly in terms of the operator's role in conducting a test and interpreting the results.

In order for ultrasonic test results to be reproducible, the variability in the above factors should be minimized, or at least subject to quantitatively defined limits. This may be readily appreciated as follows. Ultrasonic technology has great and largely unused potential for evaluating small discontinuities in solid materials. For example, many individual operators perform weld evaluations satisfactorily for a particular application; but when several operators evaluate the same specimen, different results are generally obtained. Obviously, uniformly calibrated ultrasonic instruments are not being used. Furthermore, the basic characteristics of the instruments differ. These facts contribute to the mistrust many people have of ultrasonic technology and consequently many designers do not specify use of the method.

It was recognized at MSFC that any method of overcoming the indicated difficulties must surely include the development of better ways of measuring the electrical and acoustical characteristics of instrumentation as well as the setting of sensitivity standards. An instrument of the type indicated under "Objective" is considered an essential and realistic step toward achieving the full potential of ultrasonic technology. Later in this report we suggest further steps to approach this objective.

## OBJECTIVE

The objective of this project was to design and develop ultrasonic instrumentation that will facilitate the quantitative nondestructive evaluation of material defects. More specifically, instrumentation having the following general features and containing the specified integral aids to calibration was required:

1. A high gain, broadband receiver.
2. Means of adjusting receiver gain in discrete steps.
3. Mechanical vernier adjustments to calibrate the steps in receiver gain.
4. A standard high frequency source to generate pulses of known width and amplitude.
5. Means of adjusting the transmitted pulse width and pulse repetition rate in steps of known magnitude.

6. Mechanical vernier adjustments to calibrate pulse characteristics.
7. Means of adjusting the output voltage of the transmitter continuously over a specified range. Provide an adjustment knob that can be locked.
8. Provide a voltage indicator for the output of the transmitter.
9. Means of adjusting the time base in discrete steps.
10. Mechanical vernier adjustments to calibrate the time base steps.
11. Any other features determined by mutual agreement between the contractor and representatives of MSFC.

The program to achieve these objectives was divided into four phases:

Phase I. Detailed Definition of Requirements for Instrumentation.

Phase II. Breadboard Studies.

Phase III. Fabrication and Delivery of Ultrasonic Instrument to MSFC.

Phase IV. Documentation.

#### Phase I. DETAILED DEFINITION OF REQUIREMENTS FOR INSTRUMENTATION

After reviewing contractual objectives, transducer technology and the characteristics of available ultrasonic instruments the following system parameters were analyzed:

- (a) Power and voltage level range of transmitter.
- (b) Output impedance of transmitter.
- (c) Pulse length and repetition frequency increments to be used.
- (d) The best method of developing and maintaining the accuracy of the standard calibration pulse.
- (e) Dynamic range of the receiver which is to have amplifiers with linear gain.
- (f) The number and magnitude of incremental steps in receiver gain.
- (g) Receiver bandwidth.
- (h) Input impedance of receiver.
- (i) Particular broadband transducers to be used.

- (j) The type of pulse generating circuit to be used.
- (k) Consider the possible use of standard as well as broadband transducers.
- (l) The optimum frequency range and the number of steps in that range.

After establishing detailed design requirements, a determination of fabrication procedures had to be made. More specifically, the relative practicality of using some available subsystems versus an entirely new instrument design had to be determined. It was decided to use a Tektronix R7704 oscilloscope mainframe with 7A12 and 7B52 plug-ins as a subsystem, and to design a pulser/receiver as a plug-in to that oscilloscope. It was later decided to also utilize a General Radio Type 1312 decade oscillator (10 Hz - 1 MHz) for special calibration and velocimetry applications. Other functions required special instrument development. (See frontispiece.)

Analysis of instrumentation requirements led to the following design goals, corresponding to (a) to (l) above:

- (a)  $\geq 100V$  peak-to-peak rf, with transducer load of 2500 pf;  $\geq 200V$  spike, with transducer load of 2500 pf.
- (b) Detent-adjustable from 50 to 1000 $\Omega$ ; down to 5 $\Omega$  by vernier.
- (c) Spike pulse shapes were to contain one or two transitions, each short enough to excite the transducer; rf pulse length was to be controlled by a "cycle count mode" such as 2, 4, 8, 16 or 32 cycles. Pulse repetition frequency increments of 100, 200, 500 and 1000 were selected.
- (d) Several calibration pulses or waves were to be utilized: those provided by the oscilloscope; those provided by the decade oscillator; and two special CAL functions, a rectangular shape, 0.1V by 0.5 $\mu$ s, and cw at 1, 2, 5 or 10 MHz.
- (e) Pulser/receiver dynamic linear range for its receiver section was chosen as 20 dB ( $\pm 9V$  output). The 7A12 is linear and calibrated from 5 mV to 5 V/div (60 dB) and operable to 12 V/div. Thus the total receiver range is over 86 dB.
- (f) Incremental steps of 0-2-4-...-18 dB were selected for receiver gain. Increments of 20 dB would have been redundant, since the 7A12 sensitivity is readily changed from 10 mV to 1V, to achieve a 20 dB step.
- (g) To amplify 10 MHz pulses with negligible distortion, receiver bandwidth of 30 MHz is adequate. Note that if the 5051 receiver is bypassed one can examine pulses (echoes) with the 75 MHz bandwidth associated with the 7A12.

- (h) Receiver input impedance was to be adjustable up to  $1000\Omega$ .
- (i) System must operate with typical broadband piezoelectric transducers in the 1-10 MHz range. Additionally, it was recognized that if one could operate with broadband magnetostrictive transducers, versatility would be enhanced.
- (j) Pulse generating circuits were selected as SCR for spike modes and complementary emitter follower for the rf mode.
- (k) Overshoot control was to be used, to permit use of narrowband, especially tuned, transducers.
- (l) The required frequency range was selected as 1-10 MHz, with steps at 1, 2, 5 and 10 MHz. By avoiding a front-panel selection of 2.25 MHz, the prf was enabled to be precisely 100, 200, 500 and 1000 in a synchronous fashion, derived from the rf burst frequency. To operate at any intermediate frequency, such as 2.25 MHz, an external oscillator is required, or an external frequency synthesizer, such as Hewlett-Packard 3320 A/B.

## Phase II. BREADBOARD STUDIES

In this phase we assembled a breadboard featuring most of the above provisions. To facilitate breadboard testing, we utilized a standard Panametrics pulser/receiver, model 5050 PR. This helped establish the voltages, gain, damping and bandwidth required to achieve penetration, resolution and sensitivity appropriate for applications equivalent to:

- (a) Penetration: 15 cm (6") Teflon; 1" x 6" x 6" in an ablative heat-shield material; 5 cm (2") graphite (ATJ). Graphite test showed advantage of broadband over narrowband 2.25 MHz transducers.
- (b) Resolution: ASTM No. 4 hole (1.5 mm dia, or 0.0625" dia), located about 3 mm (1/8") beneath surface, in aluminum test block. Also, impulse-induced-resonance in metal shim stock, 0.5 mm (0.020") thick.
- (c) Sensitivity: ASTM No. 4 hole, 10 cm (4") deep in aluminum.

As a result of a demonstration to W. N. Clotfelter of the breadboard at Panametrics on October 29, 1971, submission of various circuit drawings, and subsequent discussions, MSFC Contracting Officer C. C. Linn authorized us on January 21, 1972 to proceed with prototype fabrication.

It should be noted that early in the program, effort was devoted to studying step-transition transmitter waveforms, and to signal processing in the form of dual stepless gates and bipolar echo magnitude comparisons.

These studies are further described in the appendices. It was found, later in the program, that much of the single-transition results expected of the step were more easily achieved with a single-transition spike, at least for resolution problems associated with contact transducers up to 10 MHz. Regarding the signal processor (which was not required in the contract) we include in this report a design for a three-channel unit, space for which has been allowed in the delivered cabinet.

### Phase III. FABRICATION AND DELIVERY OF ULTRASONIC INSTRUMENT TO MSFC

In this phase we built and demonstrated the complete instrument or test system. To house the complete system, a Bud AGC9276RB blue cabinet was selected. To demonstrate the system's operation, and penetrating power, sensitivity, dynamic range, bandwidth, accuracy and stability, oscillograms have been included as part of the documentation. These also clarify the operating instructions.

### Phase IV. DOCUMENTATION

In this phase the appended instruction manual was prepared, describing the calibration, operation and related measuring procedures. Specific illustrative applications are included, relative to defect identification, thickness measurement, sound velocity and attenuation measurement, acoustic emission transducer testing, and moduli and Poisson's ratio measurements. These applications suggest the versatility of the prototype, and also illustrate some of its limitations. Recommendations are appended, to suggest ways of overcoming the present limitations, to achieve performance beyond the requirements of the present contract, and to approach more closely, the broad NDT objectives identified by MSFC.



## SPECIFICATIONS FOR PULSER/RECEIVER 5051

### Transmitter

- Waveforms: SPIKE S1, a single-transition pulse for maximum bandwidth, maximum penetration of highly attenuating materials. Adjustable up to 250V across 2500 pf transducer.
- SPIKE S2, a dual-transition pulse for high resolution contact testing in thin materials. Up to 200V across 2500 pf.
- RF, synchronous oscillation burst containing 2, 4, 8, 16 or 32 cycles. Frequencies: 1, 2, 5 or 10 MHz internal crystal-controlled, or 30 kHz to 10 MHz EXTERNAL oscillator-controlled. Output adjustable to 10V p-p across 1 to 10 MHz transducers, for test and calibration purposes.
- CW CAL, 1, 2, 5 or 10 MHz  $\pm 0.1\%$  continuous sine waves for calibrating scope display.
- RECT CAL, a 500 ns  $\pm 5\%$  x 100 mV pulse fed internally at prf for calibrating receiver gain. Pulse's  $t_r = 20$  ns,  $t_f = 20$  ns, for calibrating receiver bandwidth.
- Prf: 100, 200, 500 or 1000,  $\pm 0.1\%$ , internal crystal-controlled, or, in EXTERNAL mode, prf = external oscillator frequency  $\div 10^n$ , where  $n = 0, 1, 2, 3$  or 4. Suitable for overlap measurements, synchronous detection signal processing.
- Power Output Controls: Attenuator, 0-10-20 dB, and vernier, for spike S1, S2 waveforms. Internal slide switch selects 1 of 5 coupling capacitors, for optimizing energy/waveform at chosen test frequency. Damping resistor: 50, 100, 200, 1000 ohms or 1000 ohm vernier, for waveshaping (in time and frequency domains).
- Delay Control: Two-range vernier, 0.1-2, 2-20  $\mu$ s, for adjusting delay between and main bang, to permit viewing initial pulse, to compare resonant frequencies with independent cw, and, in some measurements, to center the overlapped echoes.
- Mode Test Selection: Three-position toggle switch: Transmit (1), Receive (2) or common (parallel connection of T and R).
- Pulse-Echo-Overlap Controls: Prf = EXT cw frequency  $\div 10^n$ ,  $n = 0, 1, 2, 3$  or 4. Sweep:  
(a) Internal: Triggered with an adjustable burst of synchronous trigger pulses and main bang blanking, or  
(b) External: X-axis driven by cw, and adjustable sweep blanking.
- Switch Style: Except where noted, all of above switches are Tektronix-style lit pushbuttons.
- Transducers: Piezoelectric or Magnetostrictive. Contact, buffer, immersion, pulse-echo, pitch-and-catch, through-transmission; all ultrasonic testing wave types.

### Receiver

Gain: 10X with a  $\pm 10\%$  front panel vernier adjustment.  
Bandwidth: 1 kHz to 25 MHz, 3 dB points.  
Attenuator: 0 to 18 dB in 2 dB increments.  
Noise: S1: 40 mV peak-to-peak; S2: 20 mV peak-to-peak. (output)  
Linearity: 1% at 5 MHz.  
Dynamic Range:  $\pm 9$ V.  
Input Impedance: 10,000 ohms  $\pm 5\%$ , TR switch off.  
~50 ohms, " " on.

### Mechanical

Size: 7 x 12.7 x 34.2 cm (2-3/4 x 5 x 13-1/2 in.)  
Weight: 1.45 kg (3.2 lbs).

### Mainframe

P/R plug-in is compatible with any Tektronix oscilloscope in the 7000-series.

Unlabeled  
Vernier  
Notation

### Location

Transmitter Attenuator	Below 20 dB Transmitter ATTN pushbutton.
RF Attenuator	Below RF pushbutton.
Sync Delay	Above SYNC connector.
Receiver Gain	Above RCVR OUT connector.

## SPECIFICATIONS FOR RF POWER AMPLIFIER

### Input

#### Input Signal Requirements:

Amplitude Range: 5 V pp to 15 V pp

Source Impedance:  $\leq 5 \Omega$

Signal Frequency: 1, 2, 5 or 10 MHz  $\pm 5\%$

Duty Cycle:  $\leq 10\%$

### Output

Amplitude: up to 100 V pp measured at output connector across the following capacitive loads:

FREQUENCY	MAXIMUM LOAD CAPACITANCE
MHz	pf
1	1000
2	1000
5	1500
10	2500

Output short-circuit protection is provided by a high voltage circuit breaker.

### Power Requirements

115 V 60 Hz 2.5 Amperes

Fuse: Buss MDX-3A

### Mechanical

Size: 48 x 43 x 18 cm (19" x 17" x 7")

Weight: 1.8 kg (40 lbs)

## RECOMMENDATIONS

It is understood that MSFC has both immediate and long-range plans for using the delivered instrument for quantitative nondestructive testing. In using this equipment for specific tasks, operators will undoubtedly come up with suggestions or new requirements to expand or improve the performance of the electronics. Additionally, it will be apparent that transducers may be required with specifications exceeding those presently available as standard commercial hardware items.

In order to further improve on the quantitative nondestructive evaluation of material defects, it is suggested that the following recommendations be considered:

1. Develop a pulser/receiver which retains the essential features of the 5051, yet is designed with a low-noise figure for the receiver of  $25 \mu V$  (rms). This can be achieved in several ways:
  - (a) Retain basics of present layout, but omit rf and overlap logic.
  - (b) Repackage present functions in a rack-width low-profile case, with sufficient space between boards to permit shielding and isolation, or to switch out noise sources.
  - (c) Trade bandwidth for low noise.
2. A power supply module could be designed and built to house the 5051, along the conceptual lines of Tektronix's TM501 Power Module. This would enable MSFC to use the 5051 (or a new model, type 1a above) with virtually any oscilloscope.
3. Combine a new model as in 1b with a single channel stepless gate, for spectrum analysis, alarm and recording.
4. Design and construct a three-channel signal processor (Appendix E).
5. Design and construct an automatic time intervalometer with resolution of  $\pm 1$  ns, echo polarity selections AB, AB, AB, AB, echo position selections by "blanking delay" and "echo select" modes, by two variable-position, variable-width gates, or by multiple-echo logic modes, and threshold or receiver gain control. This represents a combination of intervalometer features contained in instruments such as Panametrics' 5010, 5225X and 5220 models.

6. Design and construct an instrument for automatically measuring attenuation coefficient  $\alpha$  and reflection coefficient R. This instrument would utilize the AB and ABC ultrasonic measuring methods wherein a specimen is interrogated with a liquid or solid buffer between itself and the transducer.
7. Explore coherent detection in highly attenuating media, using phase-locked-loops, boxcar integration, etc.\*
8. Develop transducers for producing a focussed/collimated beam for high-resolution, high-sensitivity defect testing and evaluation, where the defect location is not necessarily near the surface.
9. Develop matched transducers, including development of improved ways of testing them. Example: differential comparison on 7A12.

#### ACKNOWLEDGMENT

The authors gratefully acknowledge helpful discussions with E. H. Carnevale, G. M. Elfbaum, K. A. Fowler and E. P. Papadakis of Panametrics, and with W. N. Clotfelter of NASA-MSFC.

---

\*Coherent detection and signal averaging were used for measuring low-level signals to high accuracy at the NASA Electronics Research Center several years ago. See, for example: R. C. Williamson and C. E. Chase, Phys. Rev. 176 (1), 285-294 (5 Dec. 1968); R. C. Williamson, Rev. Sci. Instrum. 40 (5), 666-670 (May 1969); R. C. Williamson, J. Acoust. Soc. Amer. 45 (5), 1251-1257 (1969); R. C. Williamson and D. Eden, J. Acoust. Soc. Amer. 47 (5) Part 2, 1278-1281 (May 1970).

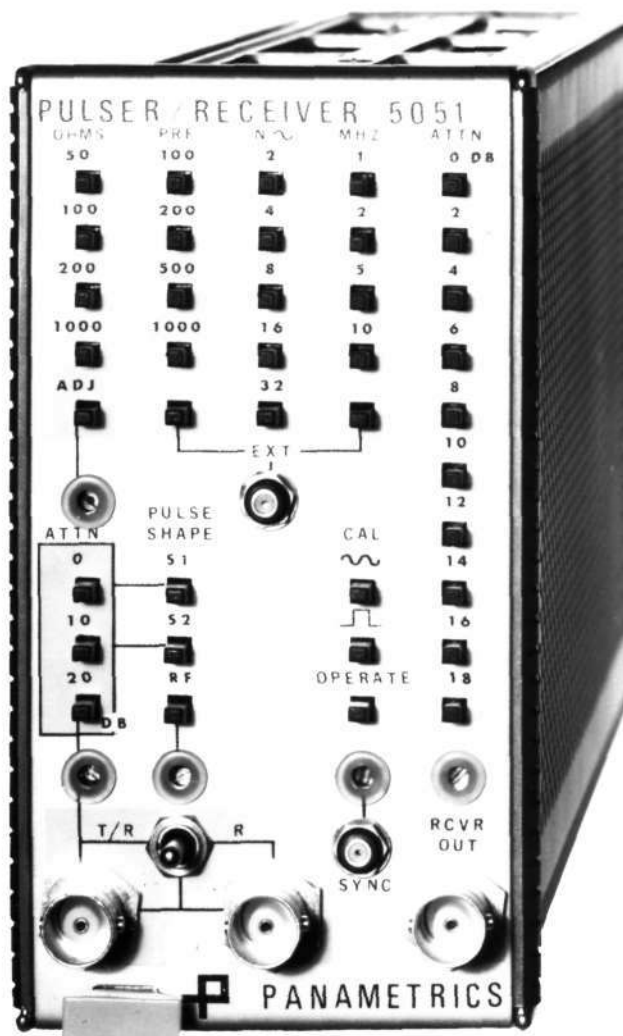


Fig. 1. Pulser/Receiver 5051.

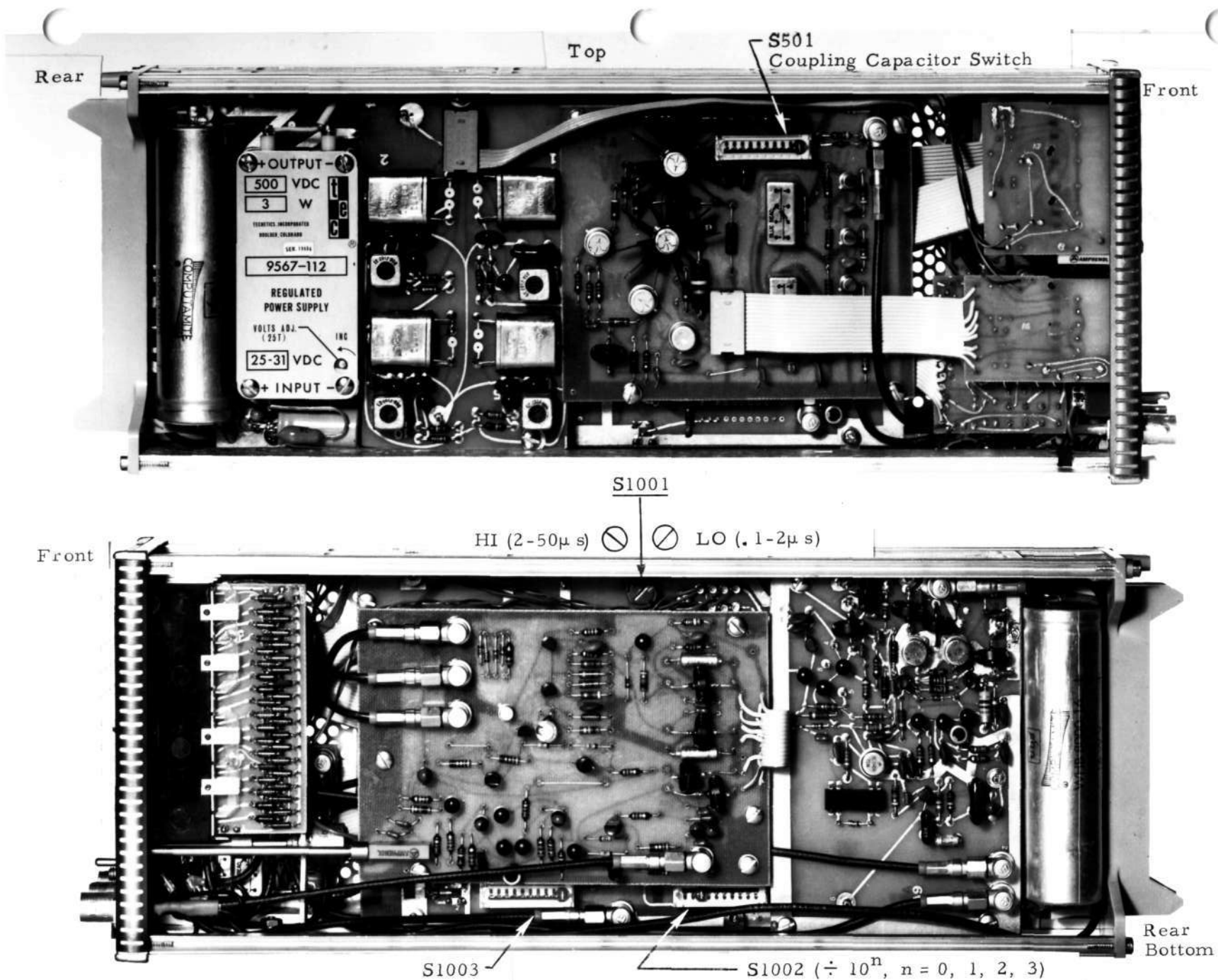
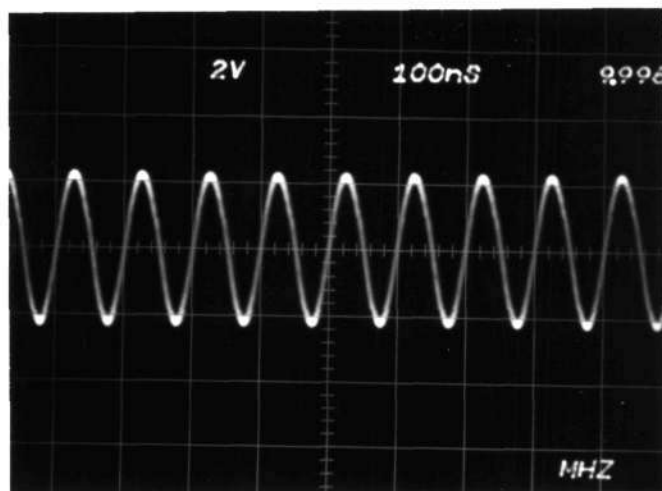


Fig. 2. Side views of Pulser/Receiver 5051 with side shield panels removed.

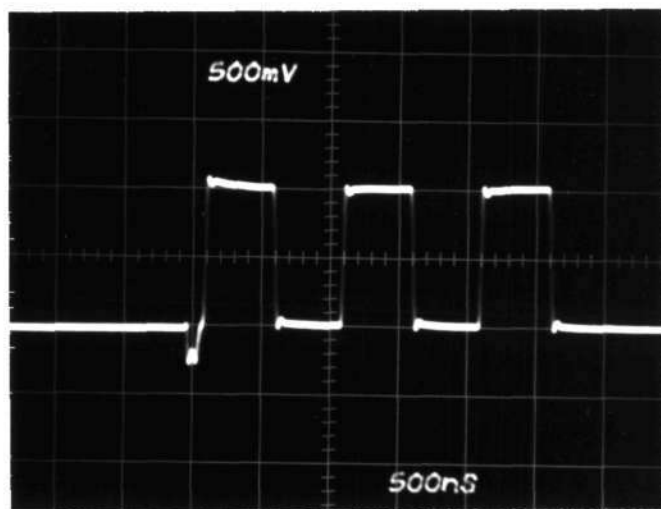
a)



# TIME BASE CALIBRATION AT 10 MHz

Settings:	Observe:
OHMS 1000	7D14 reads
PRF 1000	f = 9.996 MHz
N~ 2	
MHz 10	(At other MHz
RCVR ATTN 0	settings, 7D14 reads:
T/R Center	5.0001, 1.9984,
CAL ~	0.9975 MHz).

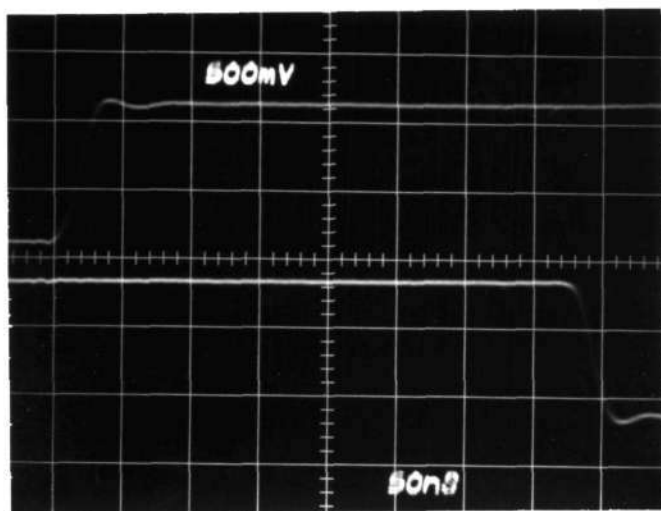
(b)



# RECEIVER GAIN CALIBRATION

CAL	⌐	Adjust Rcvr
		Gain vernier
		for 1V output.

(c)



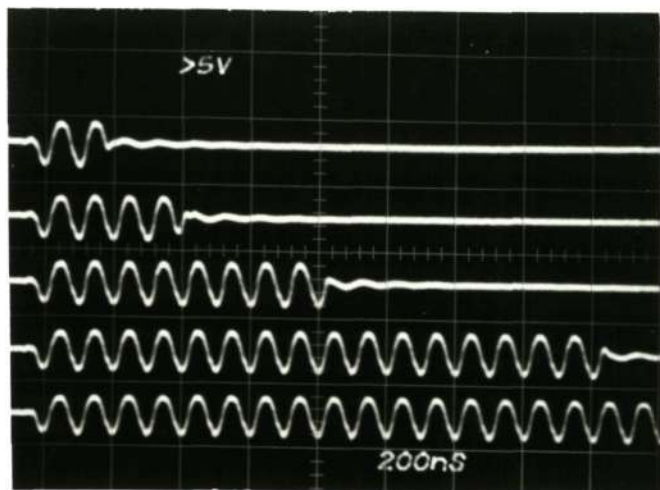
# DOUBLE EXPOSURE SHOWS RECEIVER BANDWIDTH CHECK

Observe rise and fall times at 50 ns/div.

Fig. 3. Calibration oscillograms for Pulser/Receiver 5051 plugged into Tektronix R7704 oscilloscope.



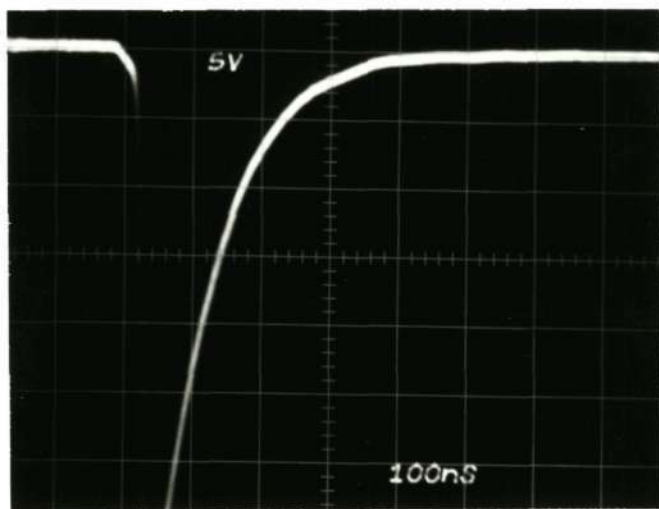
(a)



# N~ 10 MHz RF BURST OPERATION USING CYCLE COUNT MODE

Waveforms shown for open circuit load (no cable or transducer). Note > symbol in word "> 5V," meaning vertical scale is uncalibrated. Burst amplitude is approximately 10V peak-to-peak.

(b)



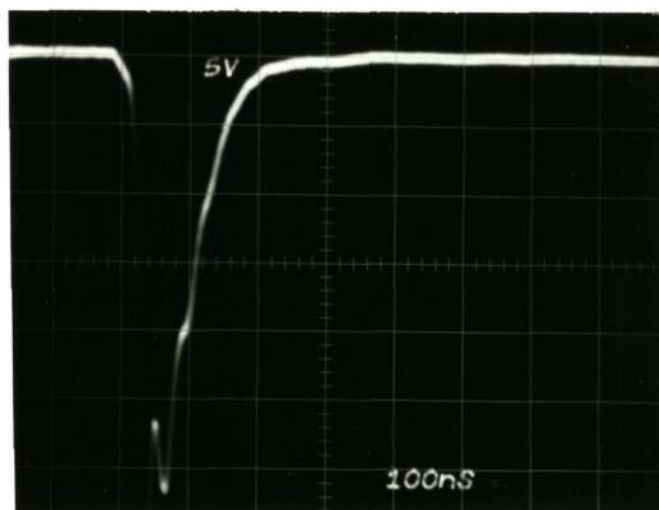
## S1 WAVEFORM, OPEN CIRCUIT LOAD

OHMS: 50.

Xmtr ATTN: 20 dB.

Trace shows open circuit voltage would exceed 300V for Xmtr ATTN of 0 dB.

(c)



## S2 WAVEFORM, OPEN CIRCUIT LOAD

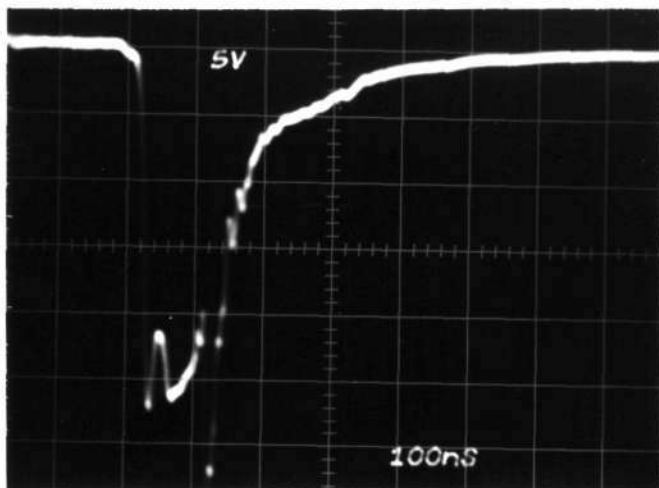
OHMS: 1000.

Xmtr ATTN: 20 dB.

Trace shows open circuit voltage would exceed 300V for Xmtr ATTN of 0 dB.

Fig. 4. Open circuit waveforms for transmitter modes RF, S1 and S2.

(a)



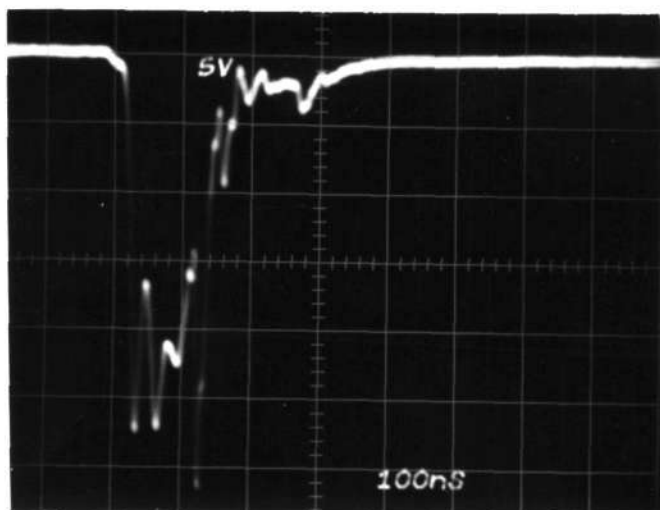
## S1 TRANSMITTER CALIBRATION

Trace shows S1 transmitter voltage can exceed 200V when driving 4 ft RG174U cable and 2500 pf transducer such as VIP-10-1/2C.

OHMS: 50.

Xmtr ATTN: 20 dB.

(b)



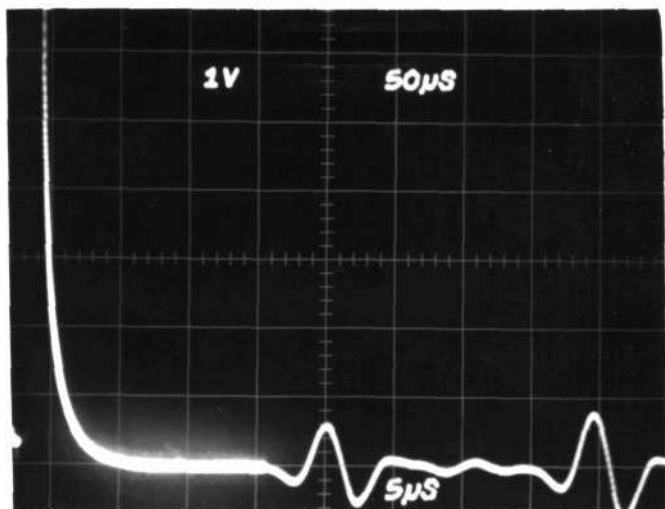
## S2 TRANSMITTER CALIBRATION

Trace shows S2 transmitter voltage can exceed 200V when driving 4 ft RG174U cable and 2500 pf transducer such as VIP-10-1/2C.

OHMS: 1000.

Xmtr ATTN: 20 dB.

(c)



S1 TRANSMITTER DRIVING L LOAD (MAGNETOSTRICTIVE TRANSDUCER 5010E5, ~100 kHz). 1" stub transducer, 16" lead-in wire, 2" specimen wire.

OHMS: 1000.

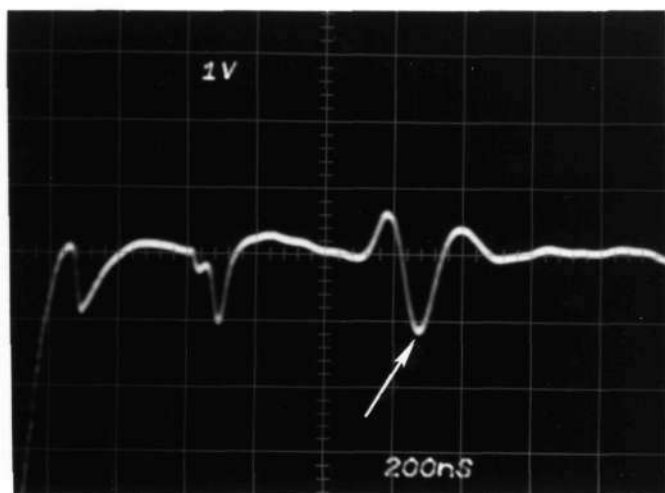
Xmtr ATTN: 10 dB.

PRF = 100.

Note 7B52 mixed sweep of 50µs for first four intensified divisions of sweep, followed by 5µs for remainder of trace, to clearly show echoes from front and rear of specimen.

Fig. 5. Transmitter waveforms for S1 and S2, observed when driving relatively large capacitive or inductive transducer loads.

(a)



## RESOLUTION TEST

ASTM #5 Flat Bottom Hole in aluminum,  $\sim 3$  mm ( $1/8$ ") below surface. Transducer: VIP-5-1/2C

S1. Xmtr, Rcvr ATTN: 0 dB.

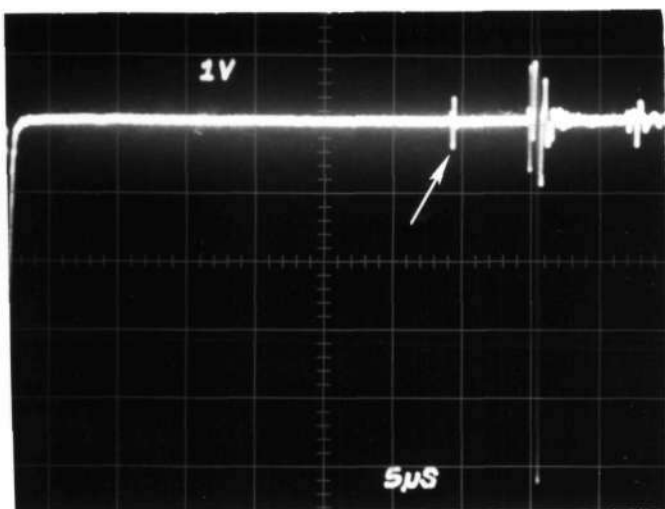
OHMS: Adjust ( $\sim 5 \Omega$ ).

PRF: 1000.

N  $\sim$  2 MHz: 10.

Arrow identifies flaw echo. Earlier "glitch" is due to TR switch.

(b)



## SENSITIVITY TEST

#5 Hole in aluminum  $\sim 10$  cm (4") below surface.

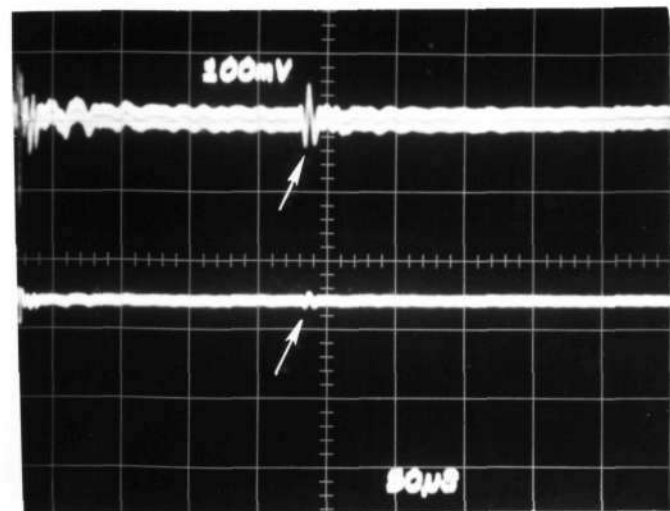
Transducer: as above.

S1. Xmtr ATTN: 10 dB.

OHMS: 50.

Arrow identifies flaw echo.

(c)



## PENETRATION TEST

Teflon,  $\sim 13$  cm ( $\sim 5.5$ ") thick.

Transducer: VIP-1-1 IT.

S1 Double exposure compares S1, S2.

Xmtr ATTN: 10 dB.

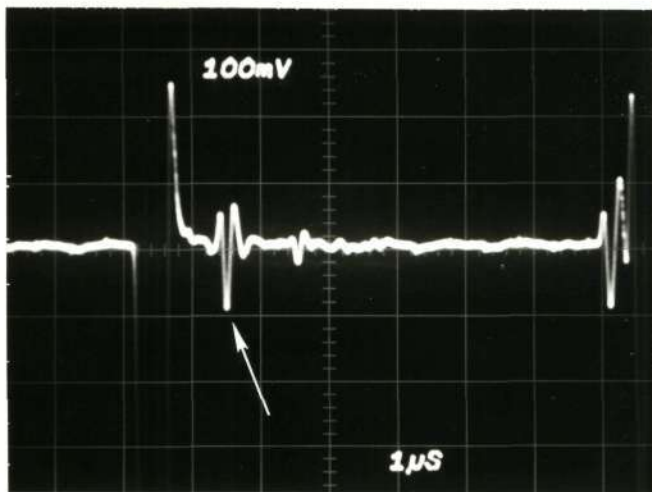
OHMS: 1000.

Scale factors: 100 mV, 50  $\mu$ s.

S2 Echoes identified by arrows are detectable, but are approaching noise limit of 5051 pulser/receiver prototype.

Fig. 6. Oscillograms demonstrating resolution, sensitivity and penetration.

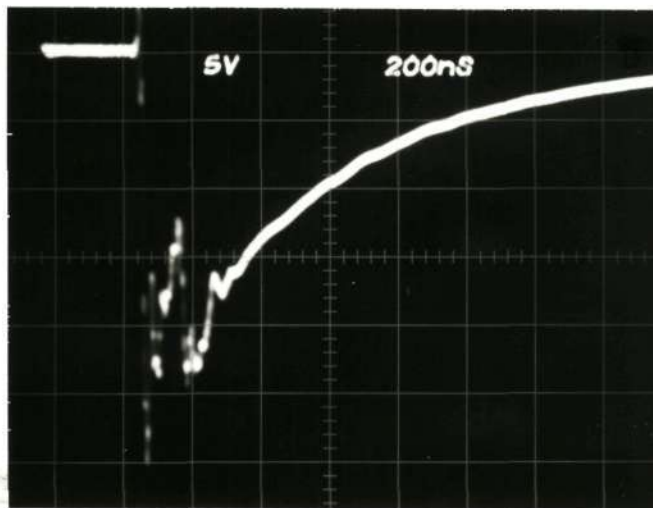
(d)



#### Immersion Test

S1            0 dB            OHMS ADJ  
              1 MHz            N = 2  
Arrow identifies echo from #5 hole located 1/8" below surface of aluminum block. Large first echo is due to water/aluminum interface.  
VIP-5-1/2C +  
1/2" water path.

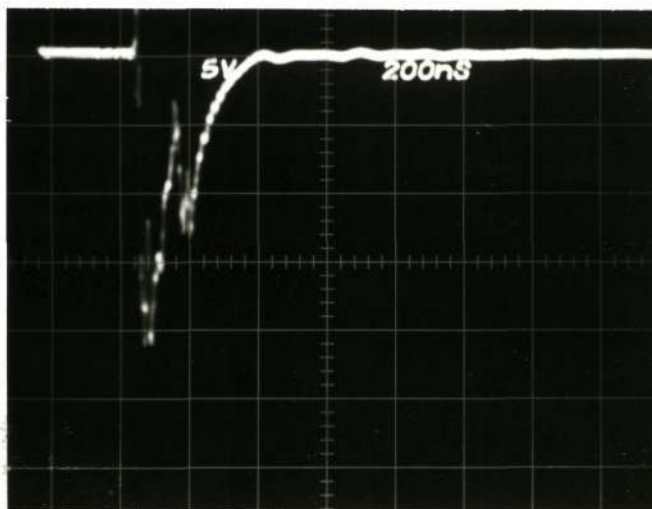
(e)



#### Transmitter output for S1.

0 dB    10X probe (50V/div)  
OHMS 1000    10 MHz  
PRF 1000    N = 2  
VIP-10-1/2C transducer.  
Observe S1 spike amplitude exceeds 300V.

(f)

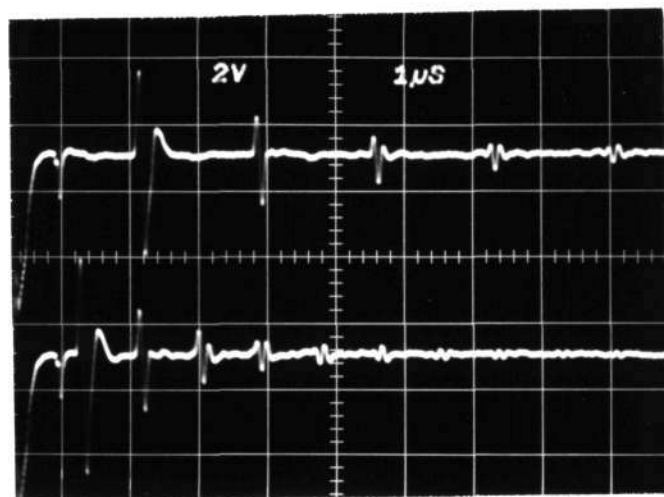


#### Transmitter output for S2. Other conditions same as **above**.

Observe S2 amplitude exceeds 200V; observe faster *recovery* to baseline.

Fig. 6, cont' d. Tests of spike mode resolution, sensitivity and voltage output into cable and 2500 pf transducer. Voltage measured for (e) and (f) at R connector with 10X probe.

(a)



FLAT STEEL  
THICKNESS

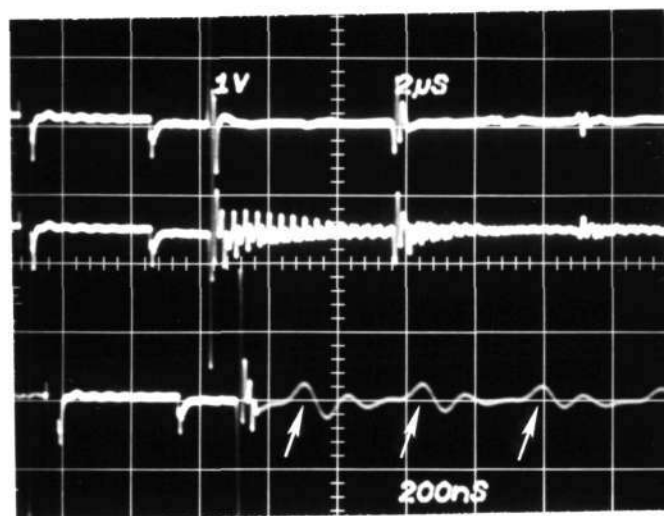
KEY 5051  
SETTINGS

S1  
. 200" (5.08 mm) Xmtr ATTN: 10 dB

OHMS: ADJ  
. 100" (2.54 mm) (< 50Ω)

VIP-10-1/2C contact transducer.  
(Note T/R switch transient at first graticule division.)

(b)



FLAT STEEL THICKNESS: .040" (1 mm)

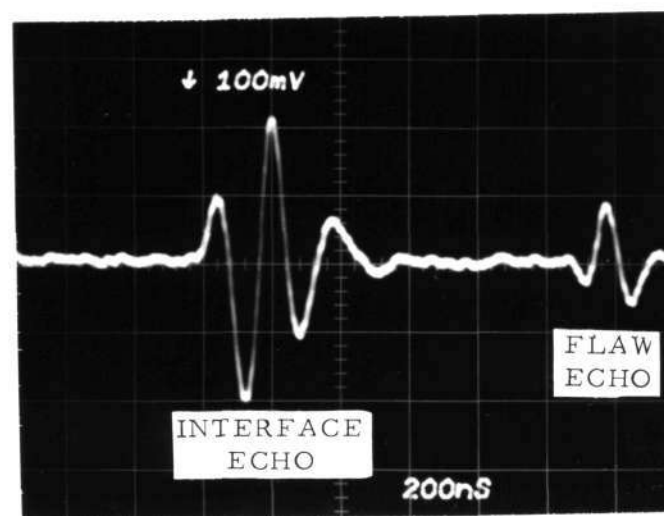
UNCOUPLED (Note buffer reverberations)

COUPLED (Note reverberations in steel specimen)

COUPLED; mixed sweep allows 200 ns/div, or 10X, expansion of trace containing specimen reverberations, indicated by arrows.

VIP-10-1/4B buffer rod transducer.

(c)



DEFECT SIMULATION: #5 Hole in aluminum, ~3 mm (1/8") below surface.

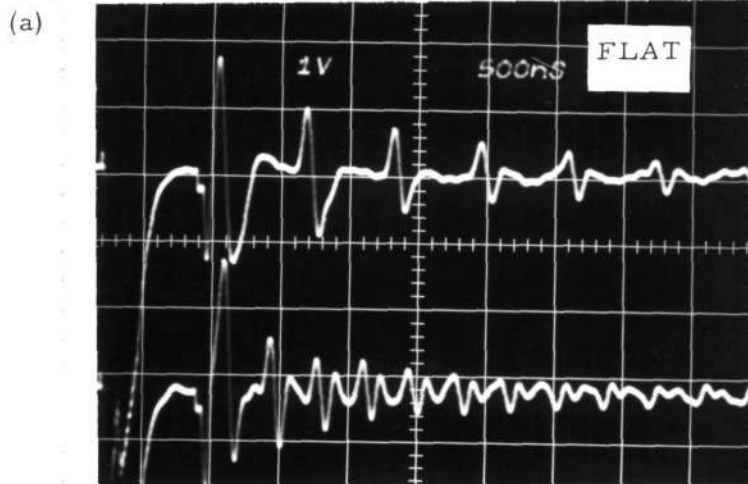
Small arrow in "↓ 100 mV" word means trace is inverted.

KEY 5051 SETTINGS: S2, Xmtr ATTN: 10 dB; OHMS: ADJ (< 50Ω); N ~: 32; MHz: 10.

VIP-10-1/4B buffer rod transducer.

Fig. 7. Resolution tests on flat surfaces using contact and buffer rod transducers.

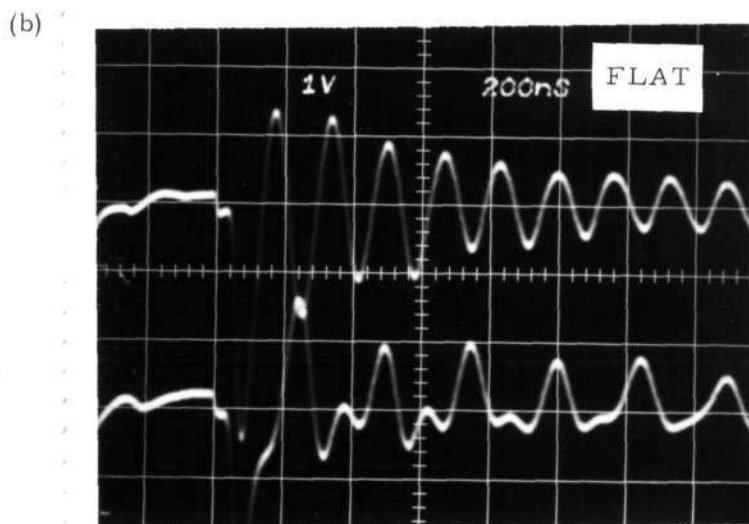




# THICKNESS

.075" (1.9 mm)

.040" (1 mm) S1 Xmtr ATTN: 10 dB  
VIP-10-1/2C OHMS: ADJ  
contact transducer.



.020" (.5 mm)

.030" (.75 mm) 5051 settings same as above. Note faster sweep, 200 ns/div.  
VIP-10-1/2C contact transducer.

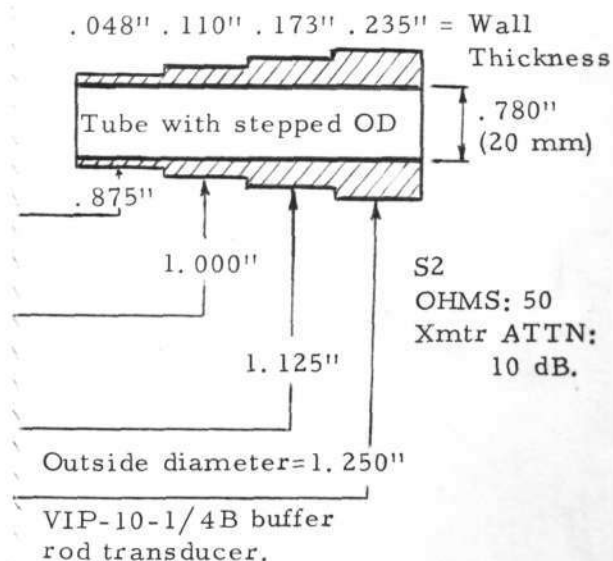
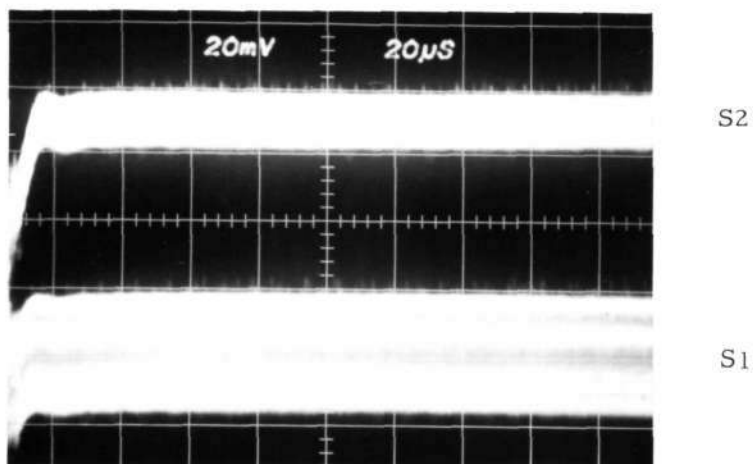


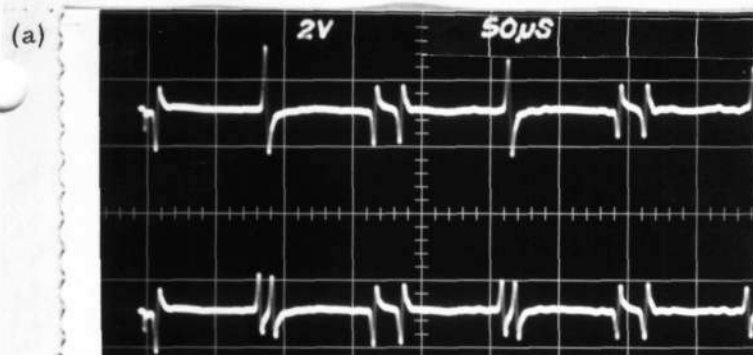
Fig. 8. Resolution tests on flat and curved steel surfaces using contact and buffer rod transducers. Flat specimens are feelers in Starrett #467 gage.



5051 KEY SETTINGS: Xmtr ATTN: 10 dB  
OHMS: 50  
N~ : 2  
T/R connector: open circuit  
(no cable or transducer)

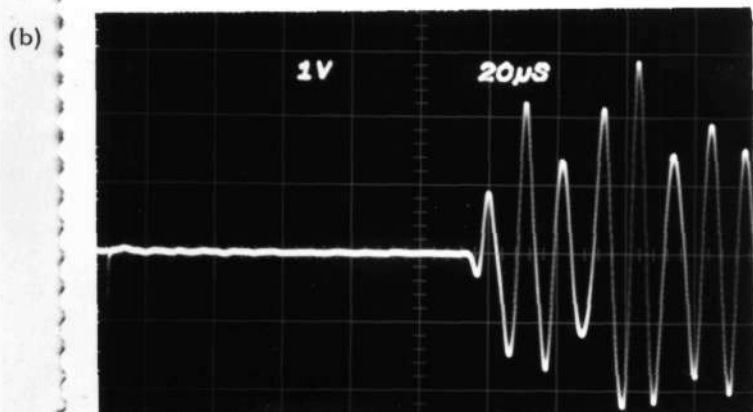
Observe noise for S2  $\approx$  20 mV peak-to-peak;  
for S1  $\approx$  40 mV peak-to-peak.

Fig. 9. Receiver noise.



S1 OHMS: 1000 PRF: 100  
Transducers: matched 5010KT55 coils, 2" (5 cm) apart, on remendur magnetostrictive wire 1/16" dia x 19" long. Centered. Observe small transient feed-through, unreflected transmission, sum pulse, pulse pair, sum, pair, etc.

Off center by 1/2". Observe small transient feedthrough, unreflected transmission, then matched pairs of different spacing and opposite polarity.



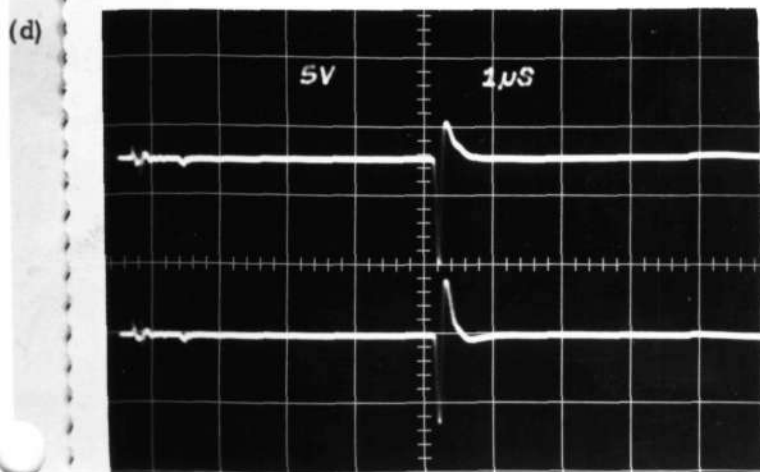
S2 OHMS: 1000 Teflon ~5-1/2" thick. Transducers: piezoelectric acoustic emission types, matched AE 0.1 L, narrow band. Observe period > 10μs, corresponding to resonant frequency just below 0.1 MHz.



S1 OHMS: 50 Aluminum block 7/8" thick

VIP-10-1/2C matched pair.

VIP-10-1/2C transmitting to VIP-1-1-IT. Note extra delay due to VIP-1 plastic wear plate, and signal differentiated by thicker 1 MHz transducer element.



S2 Steel block 1" thick. VIP-10-1/2C transmitting to VIP-5-1/2C.

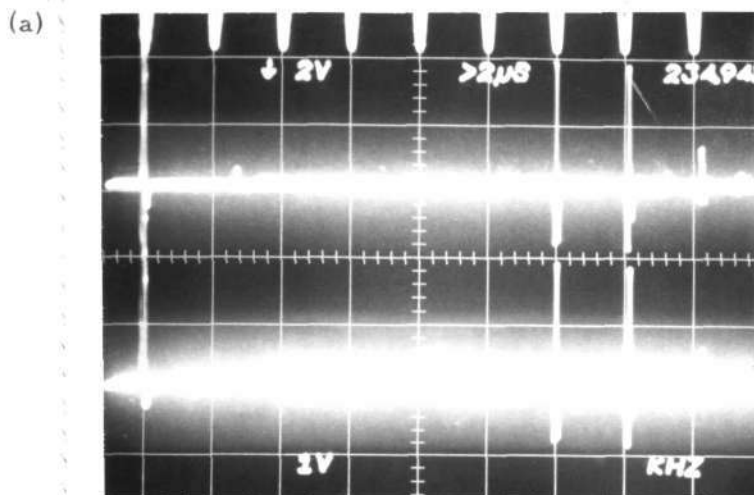
OHMS  
1000

Difference in received pulse shape primarily due to damping across transmitter. In S2 mode, receiver damping is 50Ω. Transmitter damping is 50Ω in parallel with OHMS set on 5051. For example, for upper trace, ~48Ω; for lower trace, 25Ω.

50

Fig. 10. Through-transmission tests using magnetostrictive and piezoelectric transducers from 0.1 to 10 MHz, including matched and unmatched pairs.

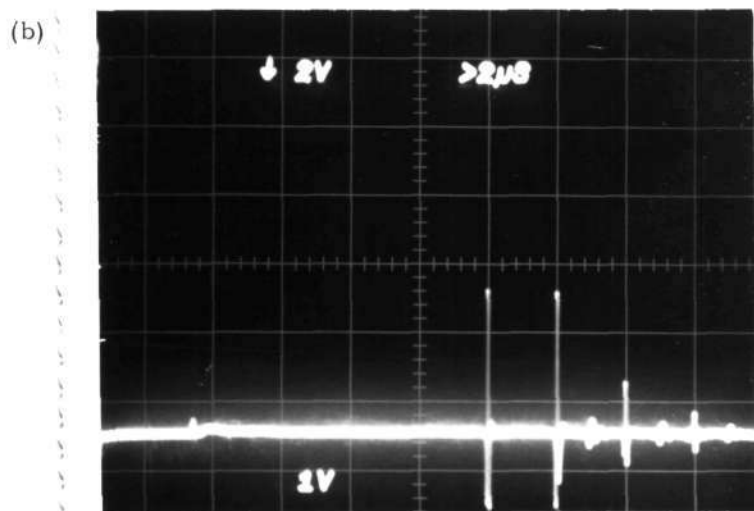




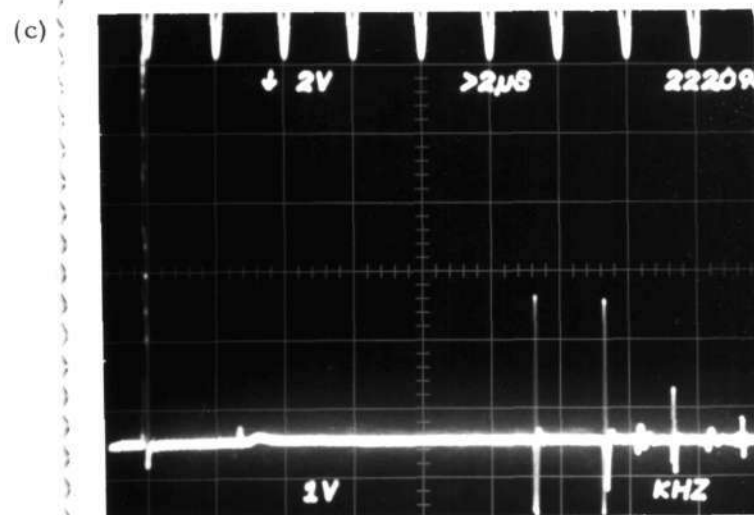
CW This sine wave of  $f = 234.941$   
 OSC kHz is used to calibrate sweep  
 so 1 div = 1" of path in material  
 of sound velocity =  $.2349''/\mu s$ .  
 (On 5051 push EXT MHz buttons.)

Adjust SYNC Delay until interface  
 echo A is aligned with a graticule  
 division.

Lower the trace position until end  
 echo B can be measured against fine  
 divisions. Path length is seen to  
 slightly exceed 1 div (1").



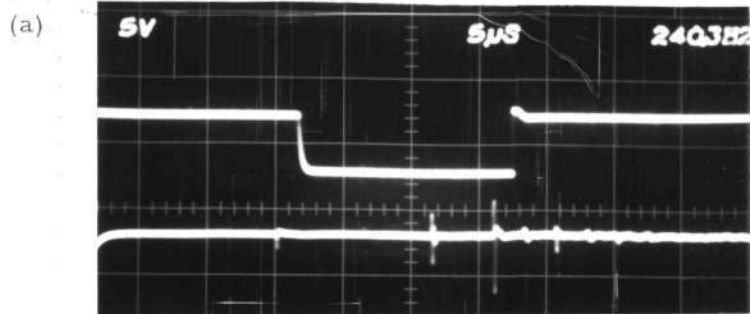
Adjust 7B52 sweep vernier until time  
 interval between A and B echoes just  
 equals 1 division.



Adjust (decade) oscillator until period  
 just equals 1 division.

Measure oscillator frequency  
 (example: using 7D14 plug-in,  
 observe  $f = 222.09$  kHz). Its  
 reciprocal is the round-trip time  
 interval, 4,503 ns.

Fig. 11. Illustration of calibrating sweep in units of velocity (top oscillogram), or of finding the frequency whose period equals the time interval, with sweep adjusted so that interval equals 1 division. Buffer is 3" steel block. Specimen is .556" steel block. Transducer: VIP-5-1/2C.



5051 SYNC output  
pedestal straddles  
specimen echoes  
A and B.

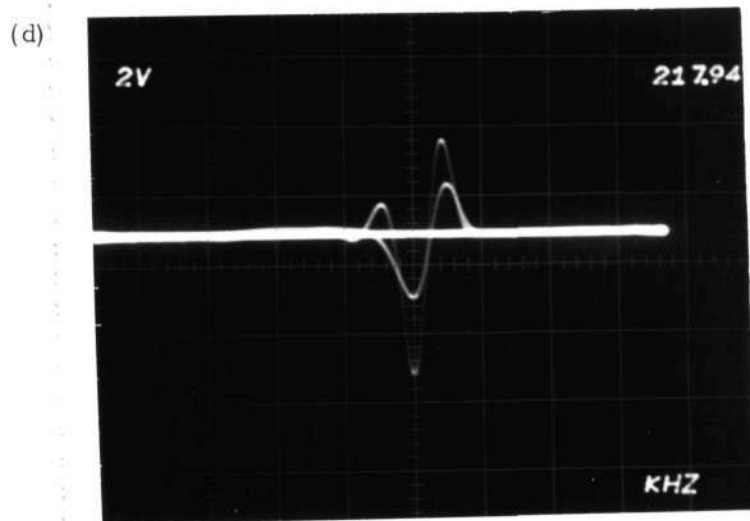
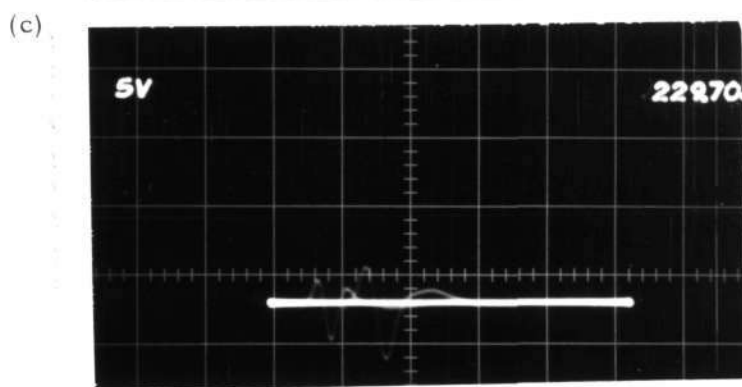
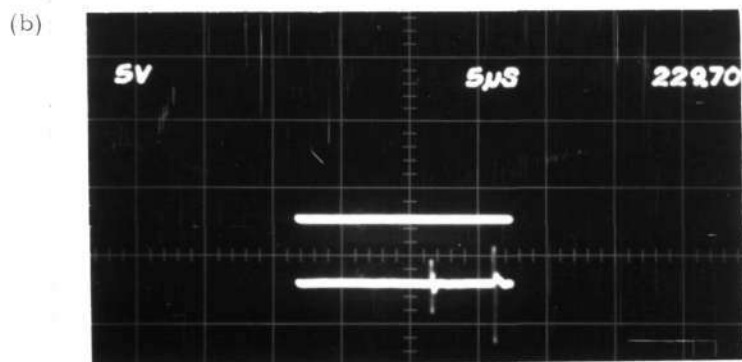
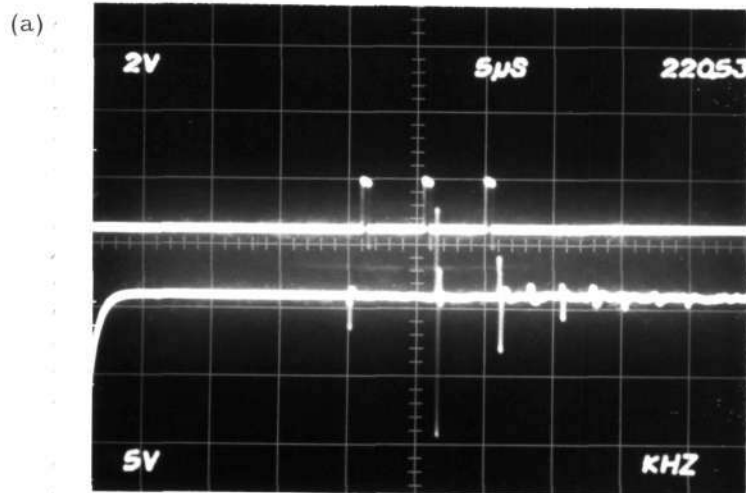
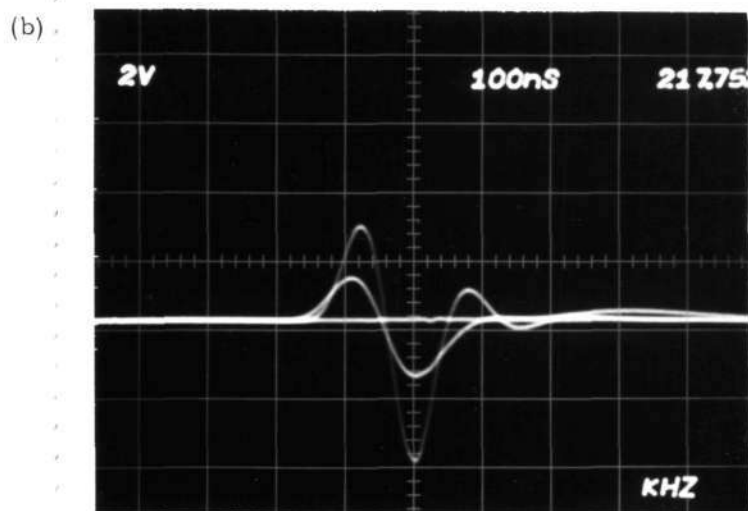


Fig. 12. Pulse-echo overlap method, driven sweep. Buffer: 3" steel block. Specimen: .556 steel block. Transducer: VIP-5-1/2C.



5051 SYNC trigger pedestals occur just prior to A and B echoes, when oscillator is adjusted to approximately correct frequency of 220.53 kHz, and N<sub>1</sub>, EXT PRF, EXT MHz and SYNC Delay set properly.

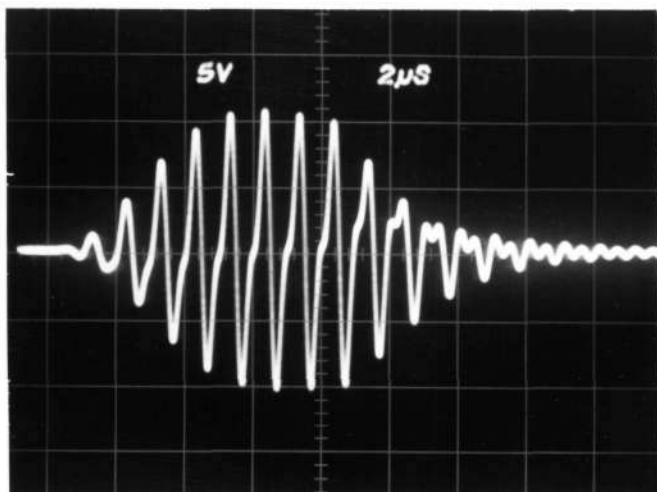


Sweep is fast enough (100 ns/div) to be retriggered in interval shorter than time between A and B ( $\sim 4.5\mu s$ ).

Sweep triggered at  $f = 217.75$  kHz. Sweep is triggered three times per main bang. Main bangs occur at  $f \div 10^2$  in this illustration.

Fig. 13. Pulse-echo-overlap method, triggered sweep.

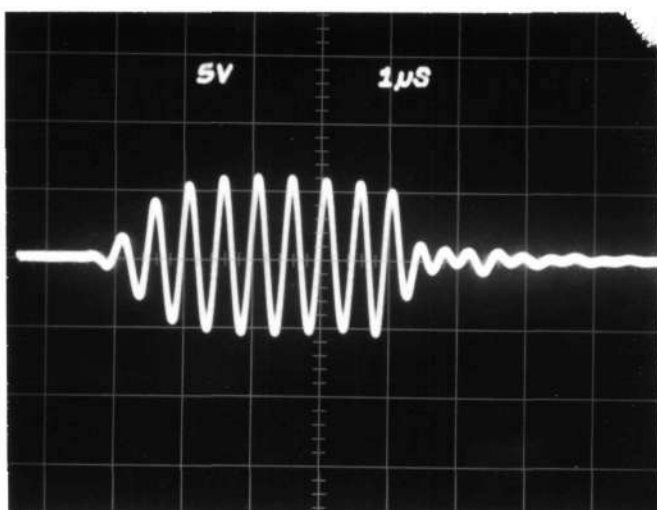
(a)



1 MHz      N = 8  
6 ft RG 58/U 50Ω cable  
VIP-1-1I transducer

Peak-to-peak voltage  
exceeds 200 V.

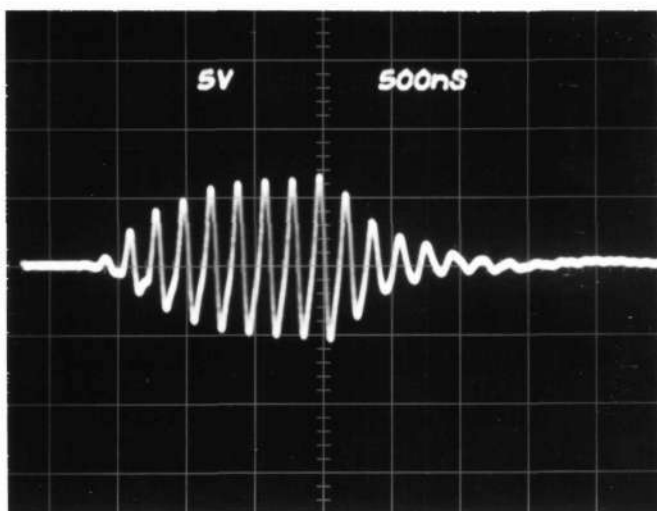
(b)



2 MHz      N = 8  
6 ft RG 58/U 50Ω cable  
VIP-2-1/4-1I transducer

Peak-to-peak voltage  
exceeds 100 V.

(c)



5 MHz      N = 8  
15 ft RG 58/U 50Ω cable  
VIP-5-1/2 C transducer

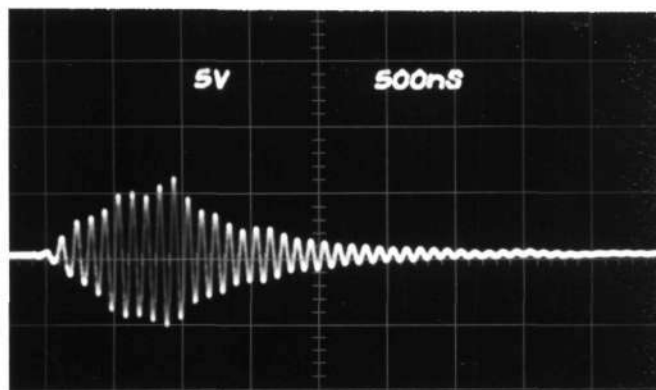
Peak-to-peak voltage  
exceeds 100 V.

Fig. 14. Test of RF Power Amplifier driving broadband transducers. Main bang monitored with 10X probe (50 V/div).

# RF OUTPUT

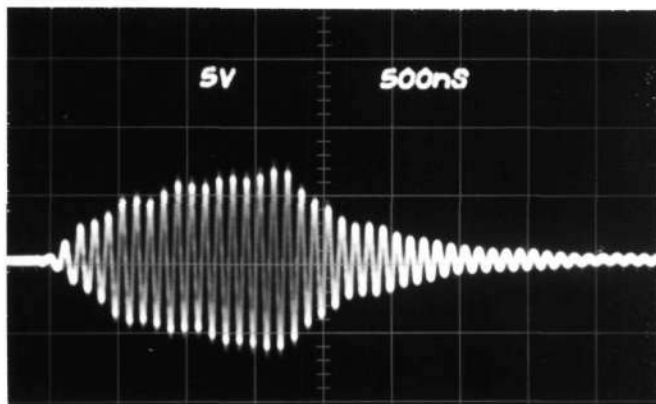
Number of cycles ( $N \sim$ )  
contained in input rf burst (10 MHz)

(d)



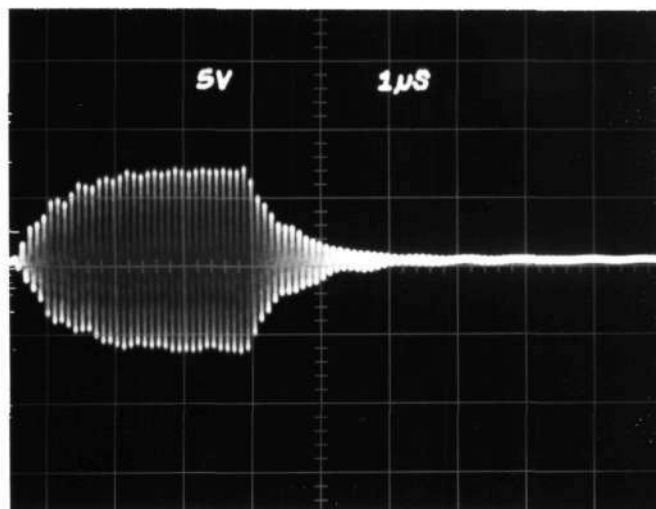
$N = 8$

(e)



$N = 16$

(f)



$N = 32$

Fig. 14, cont' d. Test of RF Power Amplifier driving VIP-10-1/2C transducer (2500 pf load) at the end of 20 ft ( $\sim 6$  m) of RG58/U  $50\Omega$  cable. (10X probe, 50V/div.)

## APPENDIX A: VELOCITY MEASUREMENT

It has been recognized for over 30 years that ultrasonic pulse-echo techniques can detect a defect large enough to be identified as an individual reflector. Such "large" or macrodefects include cracks, voids, inclusions and unbonds, of dimensions comparable to or greater than the interrogating wavelength.

During the past 15 years it has become increasingly apparent that microdefects, although of dimensions much less than the wavelength, and therefore too small to be identified individually by ultrasound, may collectively influence both sound propagation and the engineering properties of materials in a significant way. Such microdefects include porosity, density, composition and microstructure variation, strained lattices, moist areas, radiation-induced damage, etc.

Appendixes A and B briefly describe those features of the prototype ultrasonic test instrument which relate to microdefect evaluation via accurate velocity, attenuation and reflection coefficient measurements. Sound propagation measurements may sometimes be correlated with the nature and magnitude of microdefects. Engineering properties such as Young's modulus, the shear modulus, Poisson's ratio, density and sometimes grain size and texture, can be directly calculated from the measured sound velocity, reflection coefficient and attenuation.

### Methods

Sound velocity is usually determined by taking the ratio of path length to travel time. When the path length is unknown, angulation and reflection methods may sometimes be used. The present system can utilize either of these approaches.

The choice of method is largely determined by the precision or accuracy required. For example, the following accuracy limits may typically be associated with well-known methods:

Oscilloscope time base calibration	$\geq 1\%$
Oscillator/counter-assisted calibration	0.1%
Pulse- $\pi$ -point	0.01%
Overlap methods	0.001%

In this Appendix we shall briefly comment on the last three methods. For further details the reader is referred to ASTM's forthcoming E-7 Recommended Practices for Velocity Measurements.

## Oscillator/Counter-Assisted Calibration

This method is similar in principle to methods recently reported by E. H. F. Date, M. Atkins and G. V. Beaton in *Ultrasonics* 9 (4), 209-214 (Oct. 1971) and earlier by P. Mattaboni and E. Schreiber in *J. Geophys. Research* 72 (20), 5160-5163 (Oct. 15, 1967). It may also be considered an extension of conventional time-mark calibrations of the sweep at regular intervals such as 1  $\mu$ s, 100 ns, etc. (G. R. Speich et al., *Metall. Trans.* 1972).

The basic idea is to adjust the frequency of the oscillator (General Radio 1312) so the period equals the time interval to be measured. This comparison utilizes the two channels of the 7A12, plus the 5051 Sync Delay which permits one to align the peaks or zero crossings of the oscillator cw with two selected points in the signal or echo train.\* One of several variations of this idea is to adjust the sweep speed so 1 div equals a unit length in the part under test. Figure 11 illustrates typical alignment procedures. An expanded sweep provides higher accuracy.

The adjusted frequency may be measured with a Tektronix 7D14 plug-in, or with a separate counter/timer. Alternatively one may adjust a frequency synthesizer such as Hewlett-Packard 3320A/B, whose dials are direct-reading.

## Pulse- $\pi$ -Point

The pulse- $\pi$ -point method involves sweeping the center frequency of an rf burst, and recording the frequencies of successive interferences within the specimen. Papadakis has used this method over tens of megahertz, as well as below 1 MHz (*Trans. Met. Soc. AIME* 236, 1609-1613 (1966); *J. Acoust. Soc. Am.* 44, 724-734 (1968); *J. Appl. Phys.* 42, 2990-2995 (1971)). The present system is limited to use below 1 MHz by the 1312, but could operate up to at least 10 MHz if another oscillator were used instead.

## Overlap Methods

The 5051 can be operated in either of two overlap modes, besides its "normal" flaw detection mode. In one overlap mode (denoted External Overlap) the sweep is driven by the cw oscillator. In the other overlap mode (denoted Internal Overlap) the sweep is triggered an internally-controlled small number of times at a rate equal to the oscillator frequency. In either mode the final display is nearly identical, for a given group of selected echoes (Figs. 12, 13). Figures A1-A3 further illustrate the method. The following references may be useful to one interested in using the method extensively:

\*The Sync Delay would also enable one to study the motion of some bodies vibrating even at an unsteady frequency, with a stroboscopic-like display on the oscilloscope.

### Papers on Pulse-Echo-Overlap Method

- J. E. May, Jr., "Precise Measurement of Time Delay," IRE Natl. Conv. Rec. 6, Pt. 2, 134-142 (1958).
- E. P. Papadakis, "Ultrasonic Attenuation and Velocity in Three Transformation Products in Steel," J. Appl. Phys. 35, 1474-1482 (1964).
- E. P. Papadakis, "Ultrasonic Phase Velocity by the Pulse-Echo-Overlap Method Incorporating Diffraction Phase Corrections," J. Acoust. Soc. Am. 42, 1045-1051 (1967).
- E. P. Papadakis, "Effect of Multimode Guided-Wave Propagation on Ultrasonic Phase Velocity Measurements: Problem and Remedy," J. Acoust. Soc. Am. 45, 1547-1555 (1969).
- E. P. Papadakis, "Variability of Ultrasonic Shear-Wave Velocity in Vitreous Silica for Delay Lines," Trans. IEEE SU-16, 210-218 (1969).
- D. H. Chung, D. J. Silversmith, and B. B. Chick, "A Modified Ultrasonic Pulse-Echo-Overlap Method for Determining Sound Velocities and Attenuation of Solids," Rev. Sci. Instr. 40, 718-720 (1969).
- E. P. Papadakis, "Ultrasonic Attenuation and Velocity in SAE 52100 Steel Quenched from Various Temperatures," Met. Trans. 1, 1053-1057 (1970).
- J. S. Blinick and H. J. Maris, "Velocities of First and Zero Sound in Quartz," Phys. Rev. 2, 2139-2146 (1970).
- D. H. Chung, "Elasticity and Equation of State of Olivines in the  $Mg_2SiO_4$ - $Fe_2SiO_4$  System," Geophys. J. Roy. Astron. Soc. 25, 511-538 (1971).
- D. H. Chung, "Laboratory Studies on Seismic and Electrical Properties of the Moon," in The Moon, Ed. by H. Alfven, Z. Kotal, and H. C. Urey, Reidel Publ. Co., Dordrecht, Holland, March 1972, pp. 99-115.



### Velocimetry Methods Independent of Thickness

Most ultrasonic velocimetry methods are based on an equation of the form  $V = x/t$  where  $V$  = velocity,  $x$  = ultrasonic path length (i. e.,  $x$  = thickness, for through-transmission, or  $x$  = twice the thickness, for pulse-echo) and  $t$  = transit time. In contrast to these methods, there are several other methods for measuring  $V$  without requiring knowledge of  $x$ . Thus, they may be appropriate when it is not convenient to determine  $x$ , for example, when only one surface is accessible.

Critical Angle Reflectivity. This method is based on Snell's Law. It involves measuring one of several critical angles, depending on which wave type (longitudinal, shear, Rayleigh, etc.) is of interest.<sup>(1)</sup> Denoting the velocity of interest as  $V_2$ , Snell's Law gives  $V_2$  in terms of the velocity  $V_1$  and the measured initial angle of incidence  $\theta_{1c}$  in an adjacent medium (usually water) as follows:

$$V_2 = V_1 / \sin \theta_{1c} .$$

This method has been described in greater detail by Rollins<sup>(2)</sup> and by Becker.<sup>(3)</sup>

This method may be practiced using the present system. On the 7B52, the TIME/DIV may be rotated full ccw to AMPL, and the horizontal deflection may then be driven in proportion to the angle of incidence  $\theta_1$ . The linearity and DC OFFSET of the 7A12 may then be utilized, to obtain a pattern of reflected amplitude vs  $\theta_1$ .

Differential Path or Differential Angle. This method, of limited use, is also based on Snell's Law, and may be considered, when it is not convenient to measure  $x$  or  $\theta_{1c}$ . It may be understood by applying Snell's Law twice, for two different angles of incidence. Let the incident angles be denoted  $\theta_{1a}$  and  $\theta_{1b}$ , as in Fig. A4. Consider the two refracted rays of like mode in medium 2, which will travel along different paths at refracted angles  $\theta_{2a}$  and  $\theta_{2b}$ . They will be reflected after traveling in medium 2 for intervals  $t_p$  and  $t_q$ , respectively. Again denoting the velocity in medium 1 as  $V_1$ , if we define  $A \equiv \sin \theta_{1a} / V_1$  and  $B \equiv \sin \theta_{1b} / V_1$ , it may be shown that, for isotropic media,

$$V_2 = \sqrt{\frac{1 - (t_p/t_q)^2}{B^2 - A^2 (t_p/t_q)^2}} . \quad (A1)$$

As a special simplifying case, we may let  $\theta_{1a} = 0$  (normal incidence).

Then  $A = 0$  and  $V_2 = (1/B) \sqrt{1 - (t_p/t_q)^2}$ .

The practical difficulty stems from trying to measure directly the transit time in the specimen  $t_q$  for the wave at oblique incidence. Of perhaps academic interest, one might determine  $t_q$  by timing the interactions of a laser beam with the echoes, where the laser in effect monitors at least one surface of the specimen. This would of course be limited to wedges and/or specimens which were optically transparent, and would be a relatively complicated measurement in any event.

In principle, one can also determine  $V_2$  in terms of the transit time  $t_p$  measured at normal incidence, and the distance  $2W$  along the specimen surface between a pair of symmetrical "pitch-and-catch" wedge transducers, when the distance between these transducers is adjusted for the maximum echo amplitude. It may be shown that, for the geometry of Fig. A5, and provided the same mode is used in determining  $t_p$  and  $W$ ,

$$\frac{V_2^2}{\sqrt{V_1^2 - V_2^2 \sin^2 \theta_{1b}}} = \frac{W}{t_p \sin \theta_{1b}} \quad (A2)$$

Now if the wedges are such that  $\theta_{1b} = 45$  deg and  $V_1 = 0.5$  cm/ $\mu$ s, this simplifies to

$$V_2^2 / \sqrt{1 - 2 V_2^2} = 0.354 W/t_p \quad (A3)$$

To solve this for  $V_2$ , one may use Table A1 or a graph of  $V_2$  vs  $W/t_p$  (Fig. A6) or iterative procedures, provided  $V_2 < 0.707$ .

Equations (A2) and (A3) also apply for a procedure similar to that used in critical angle reflectivity, where, if the distance between two variable-angle symmetrical wedges were fixed, one could vary the oblique angles until a maximum reflection from the specimen's rear surface was observed. One denotes this particular (but not critical) angle  $\theta_{1b}$ . From this angle  $\theta_{1b}$ , the wedge velocity  $V_1$ , the wedge distance  $2W$  and the time interval  $t_p$  measured at normal incidence,  $V_2$  can be calculated.

Table A1. Solutions to Eq. (A3) for  $\theta_{1b} = 45 \text{ deg}$   
and  $V_1 = 0.5 \text{ cm}/\mu\text{s}$ .

<u><math>V_2, \text{ cm}/\mu\text{s}</math></u>	<u><math>W/t_p, \text{ cm}/\mu\text{s}</math></u>
0.1	0.029
0.2	0.118
0.3	0.280
0.4	0.548
0.5	1.00
0.6	1.92
0.7	9.80

\*\*\*\*\*

#### Reflection Coefficient

In this method  $V_2$  is derived in terms of the sound pressure reflection coefficient  $R$ .<sup>(4,5)</sup> One can measure  $R$  at normal incidence, at the interface between a first medium (liquid or solid) of known characteristic impedance  $Z_1$ , and the second medium. That is, one measures  $R = -E_{\text{coupled}}/E_{\text{free}}$ , where the  $E$ 's are the echo amplitudes observed when the two media are coupled and then uncoupled, respectively, for a wave in medium 1 impinging on medium 2. Provided the density  $\rho_2$  in medium 2 is known or measurable, the velocity  $V_2$  may be determined from:

$$V_2 = \frac{Z_1}{\rho_2} \frac{1+R}{1-R} . \quad (\text{A4})$$

#### Velocity Ratios

In some instances it may be useful to determine the ratio of two velocities, over a common path.<sup>(6)</sup> This is sometimes easier to do than to determine just one velocity, when the path length  $x$  is unknown.<sup>(7)</sup> The velocity ratio for longitudinal and shear waves is simply the reciprocal of the corresponding transit time ratio:

$$\frac{V_T}{V_L} = \frac{t_L}{t_T} . \quad (\text{A5})$$

Poisson's ratio  $\sigma$  may be written in terms of these ratios:

$$\sigma = \frac{1 - 2 (V_T/V_L)^2}{2 - 2 (V_T/V_L)^2} . \quad (A6)$$

Conversely, the velocity ratio may be expressed in terms of  $\sigma$ :

$$\frac{V_T}{V_L} = \sqrt{\frac{1 - 2\sigma}{2(1 - \sigma)}} . \quad (A7)$$

In the case of specimens such as round wires or thin rods of diameter small compared to wavelength, such that, instead of longitudinal waves, one has extensional waves propagating at a velocity  $V_E = \sqrt{E/\rho}$  where  $E$  = Young's modulus and  $\rho$  = density, and torsional waves propagating at  $V_T = \sqrt{G/\rho}$  where  $G$  = shear modulus, the thin rod velocity ratio is:(8)

$$\frac{V_T}{V_E} = 1/\sqrt{1 + \sigma} . \quad (A8)$$

## References

1. R. C. McMaster, ed., Nondestructive Testing Handbook, Vol. II, 45.9-45.12, Ronald Press Co., New York (1959).
2. F. R. Rollins, Jr., Materials Evaluation 24, 683 (1966); Int'l. J. NDT 1 (2), 127-145 (July 1969).
3. F. L. Becker and R. L. Richardson, in: R. S. Sharpe, ed., Research Techniques in Nondestructive Testing, Chap. 4, 91-131, Academic Press, N. Y. (1970).
4. L. C. Lynnworth, Materials Evaluation 29 (2), 27A (Feb. 1971).
5. L. C. Lynnworth, Materials Evaluation 30 (10) (Oct. 1972).
6. R. C. McMaster, ed., Nondestructive Testing Handbook, Vol. II, 43.10, Ronald Press Co., New York (1959).
7. L. C. Lynnworth and E. H. Carnevale, 300-307, in: Proc. 5th Int'l. Conf. NDT, Montreal (May 1967).
8. N. S. Tzannes, IEEE Trans. Sonics and Ultrasonics SU-13 (2), 33-41 (July 1966).

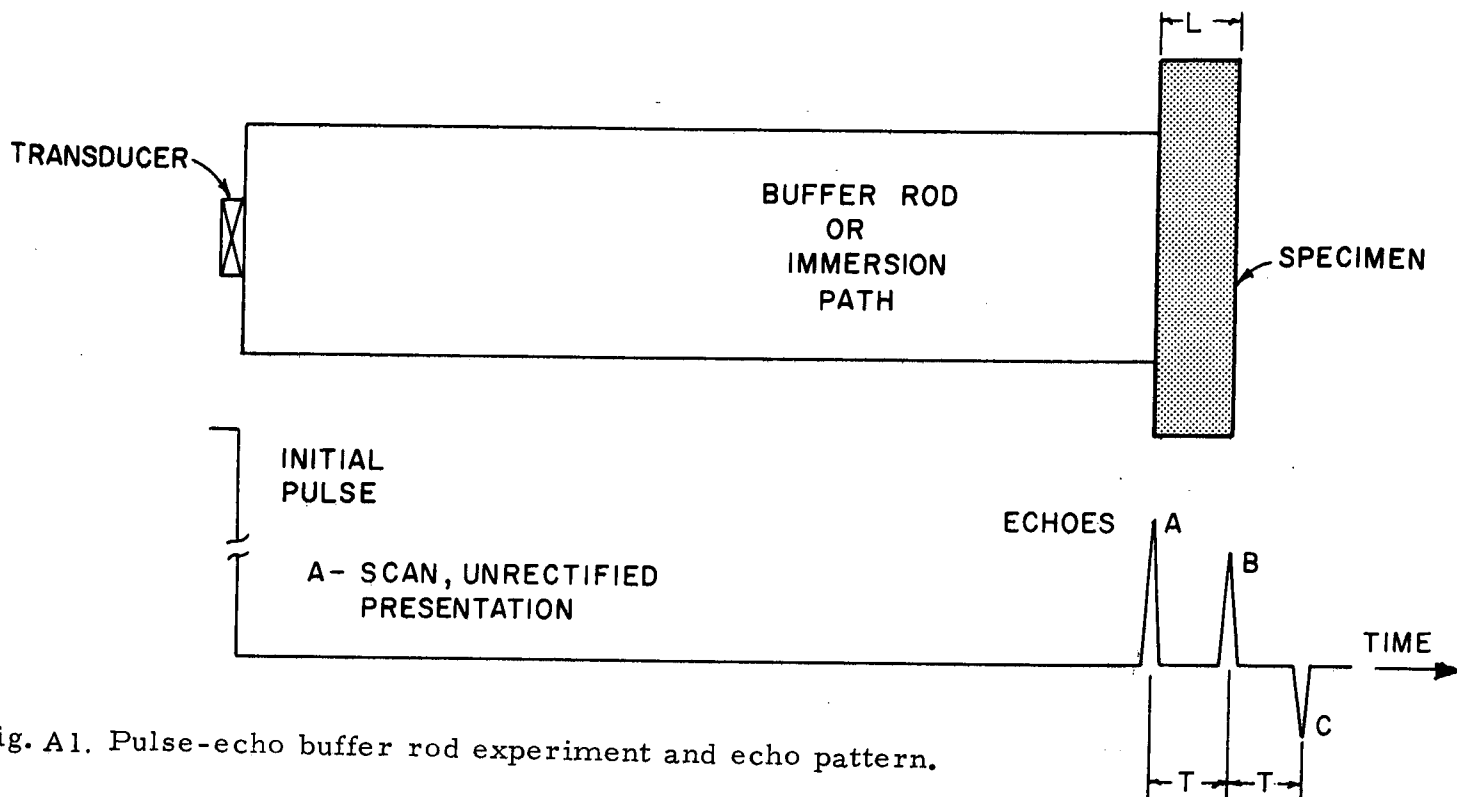


Fig. A1. Pulse-echo buffer rod experiment and echo pattern.

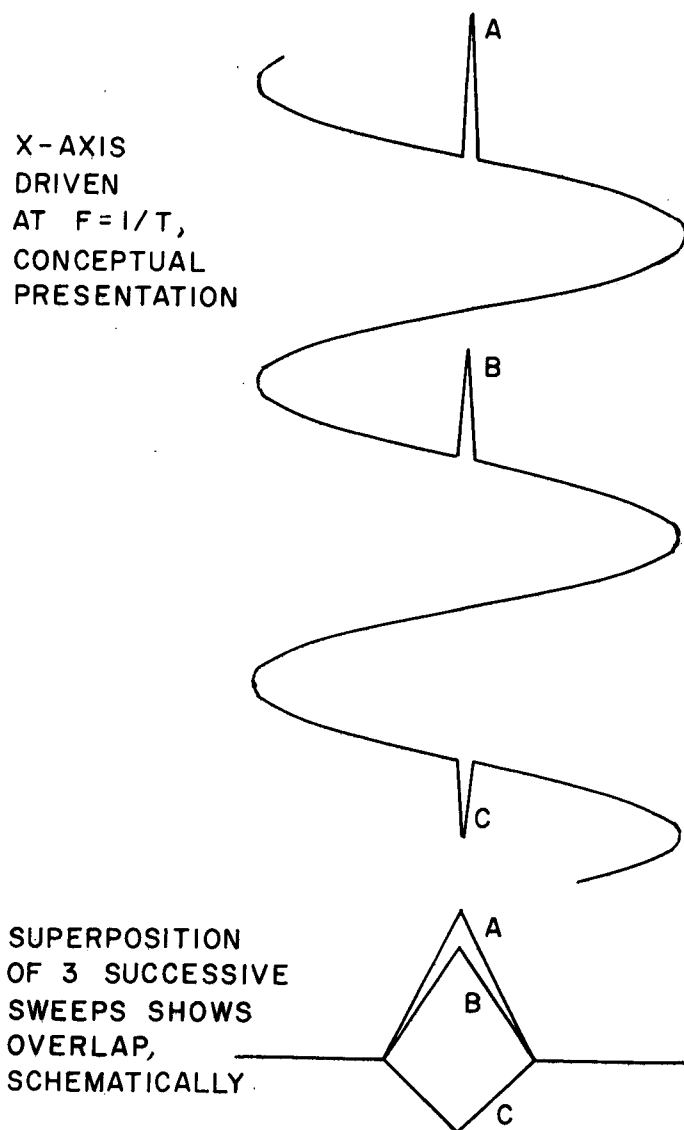
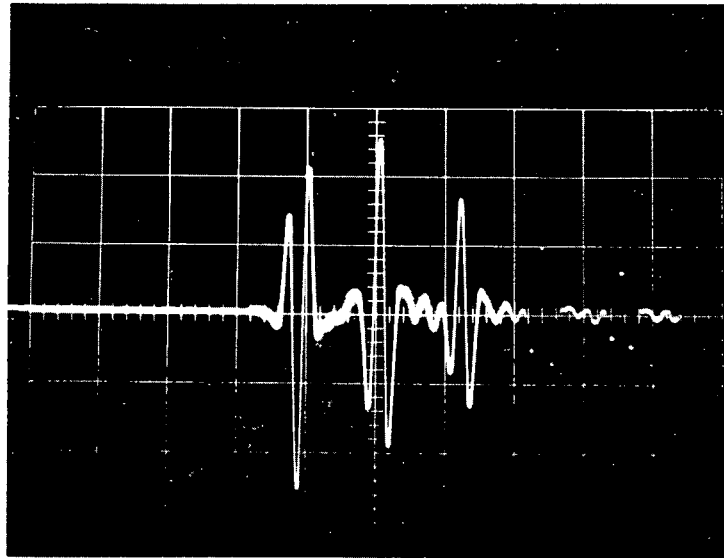
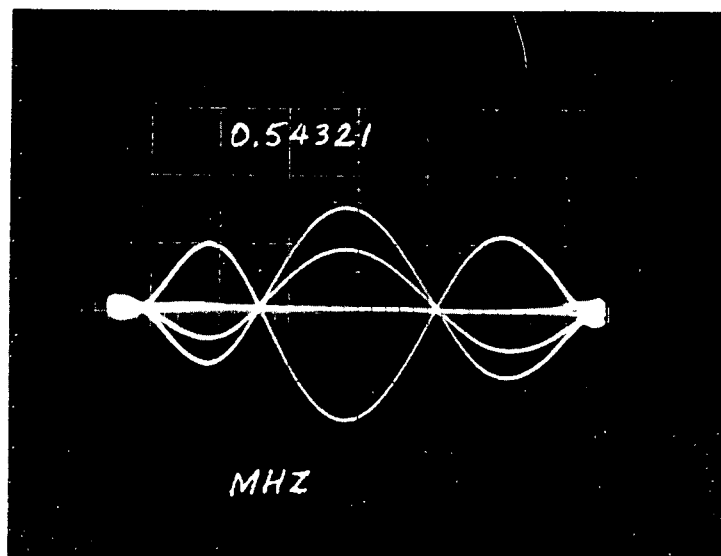


Fig. A2. Pulse-echo-overlap method illustrated for echoes A, B and C.



LINEAR SWEEP



(Retouched)

DRIVEN SWEEP

Fig. A3. Top: Three echoes intensified for the pulse-echo-overlap measurement. Bottom: These echoes overlapped by driving the x-axis of the oscilloscope with a frequency equal to the reciprocal of the travel time between echoes.

Fig. A4. Velocity determination based on principle of measuring travel times in specimen of two oblique rays.

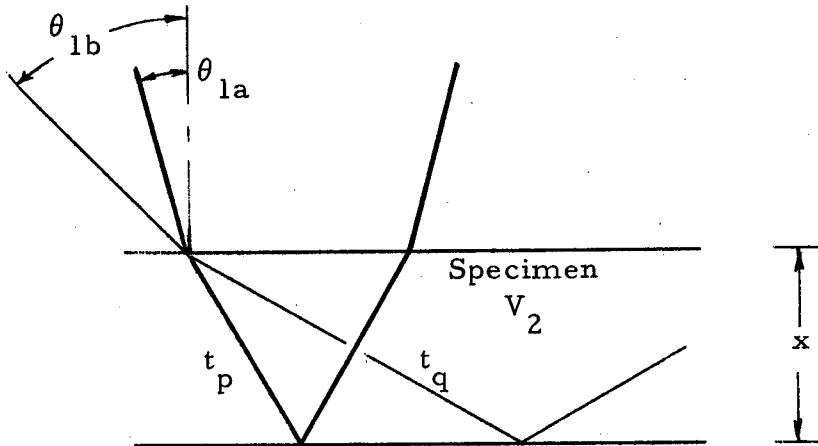


Fig. A5. Velocity determination based on travel time  $t_p$  at normal incidence, and the distance  $2W$  between symmetrical wedges positioned for maximum echo amplitude.

Wedge:  $V_1 = 0.5 \text{ cm}/\mu\text{s}$

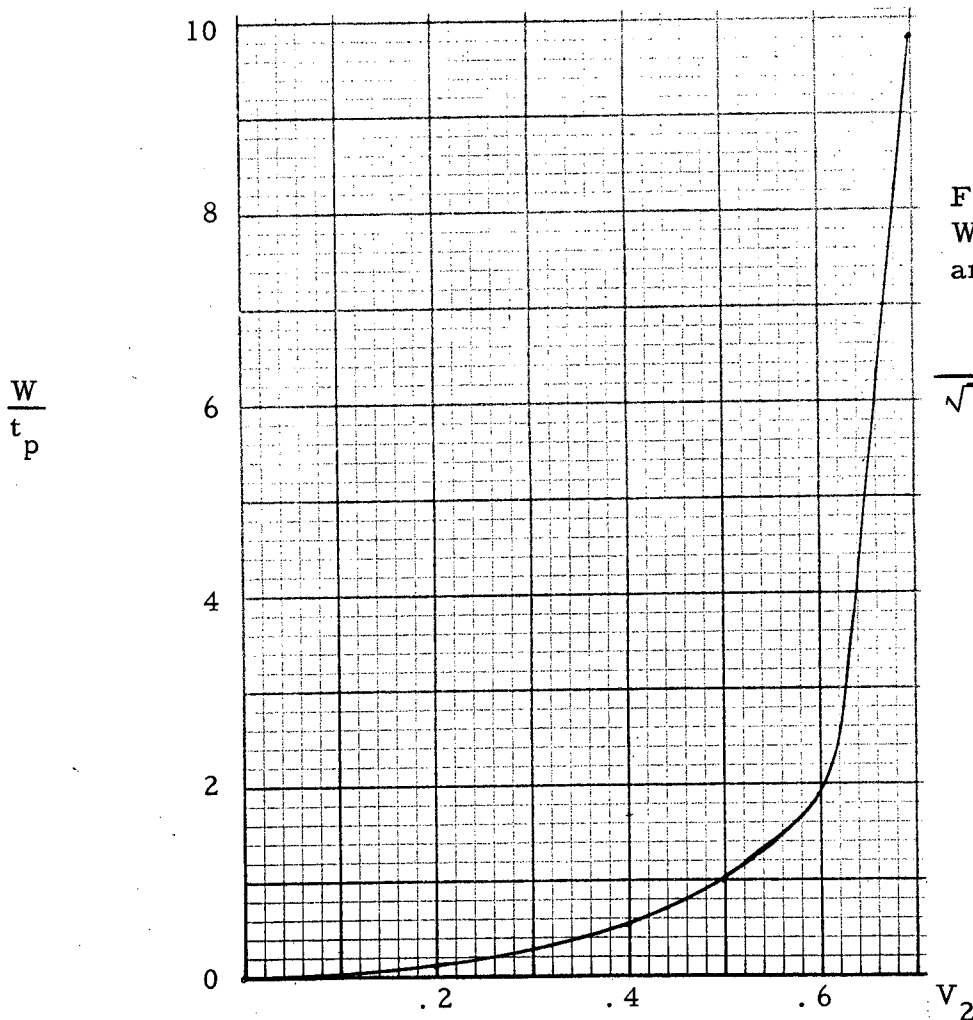
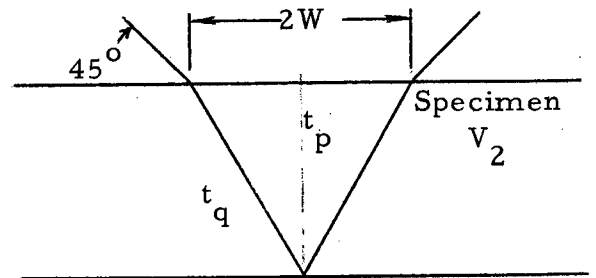
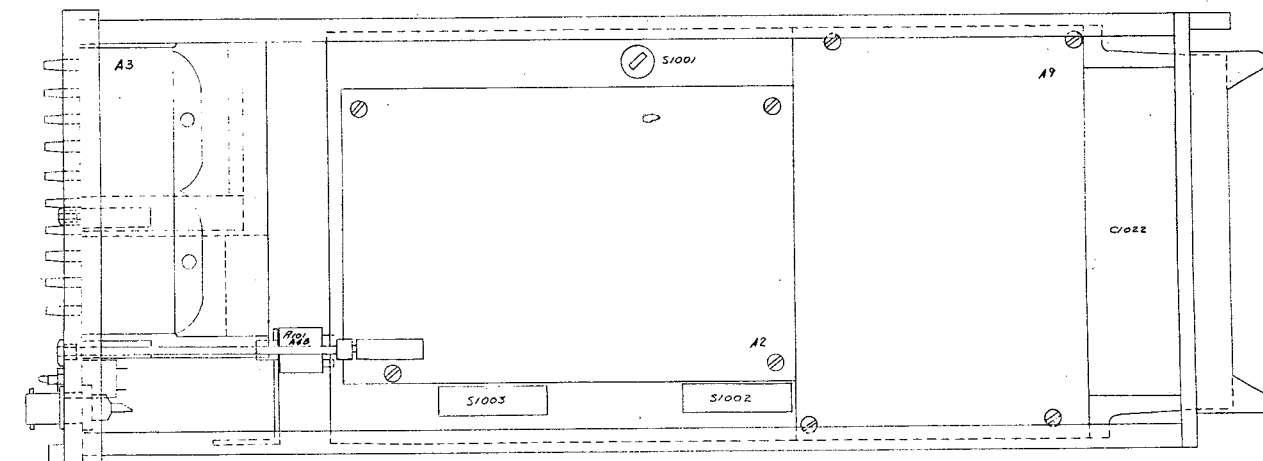
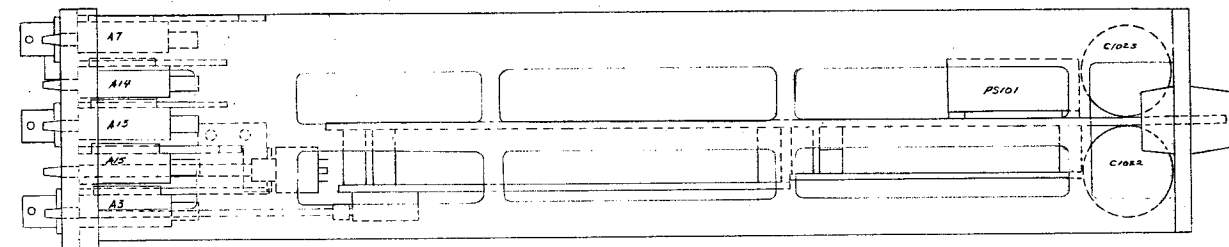
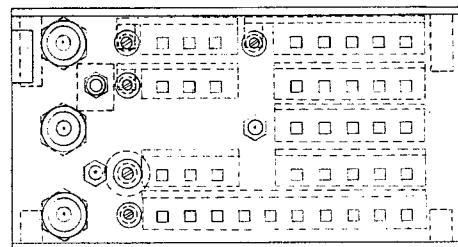
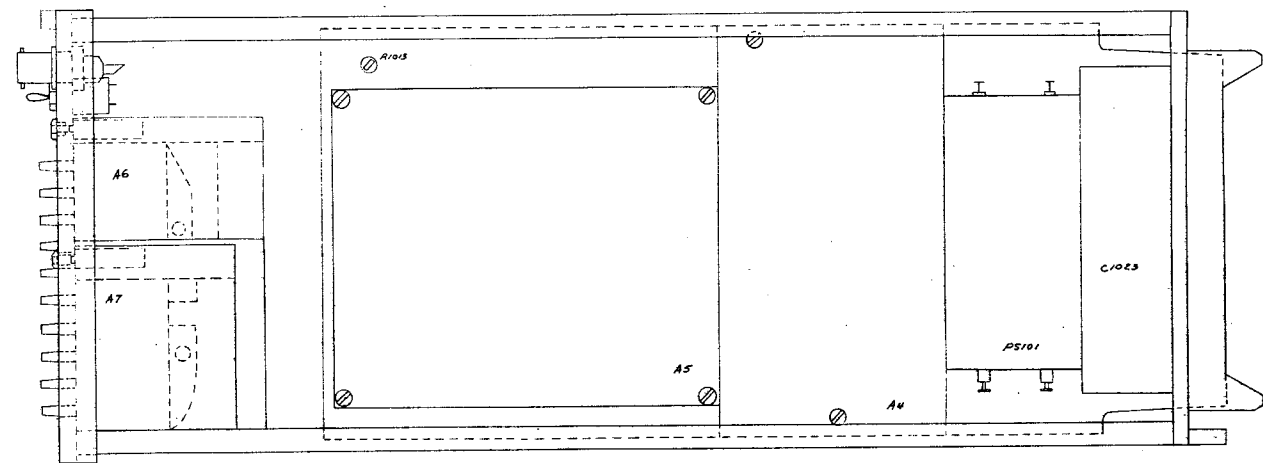


Fig. A6. Graph of  $W/t_p$  vs  $V_2$  for geometry and conditions of Fig. A4:

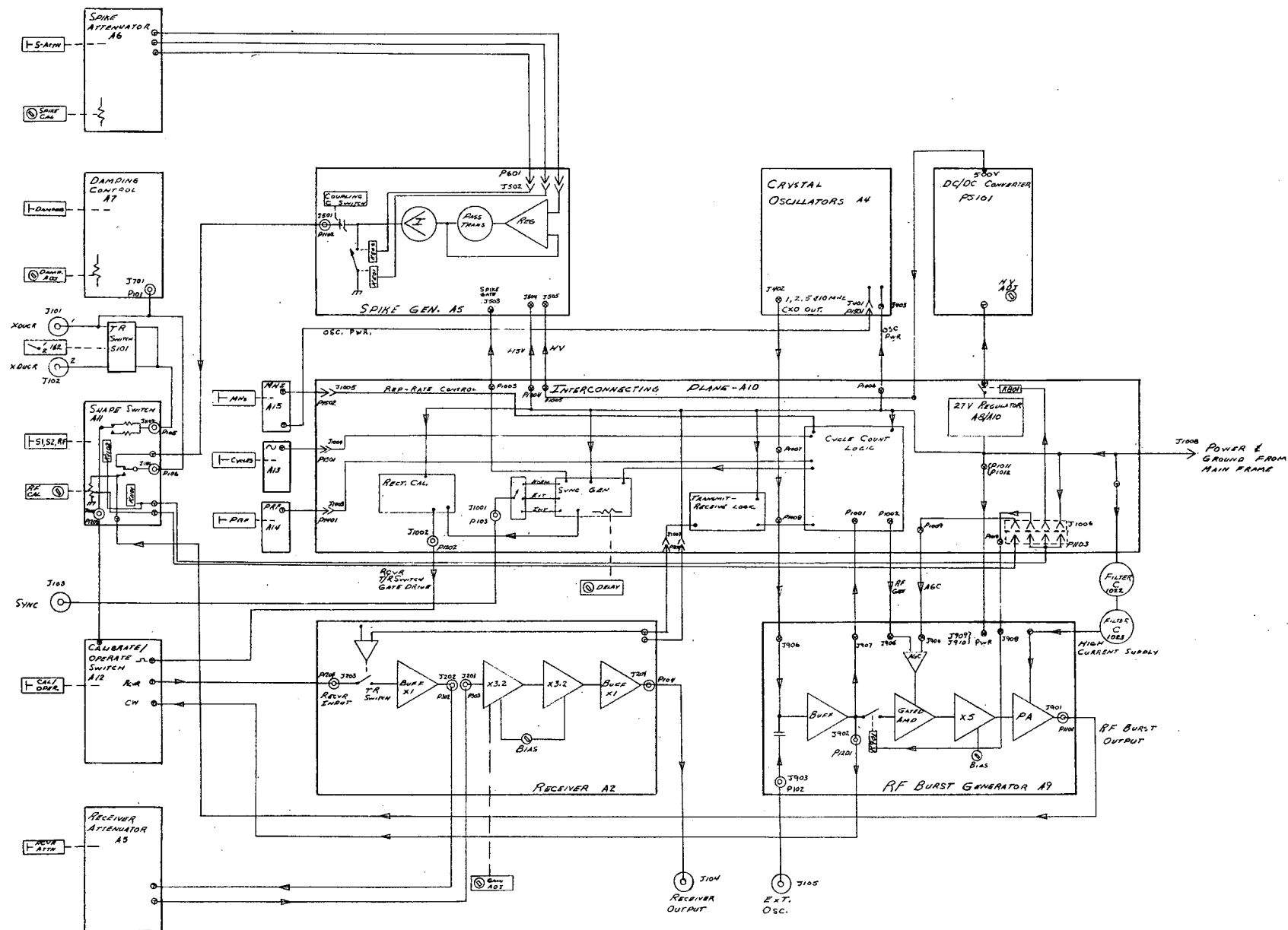
$$\frac{V_2^2}{\sqrt{1 - 2V_2^2}} = 0.354 \frac{W}{t_p}$$





REVISIONS			PULSER-RECEIVER MECHANICAL ASSY...		
NO.	DATE	BY			
1					
2					
3					
4					
5					
			DRAWN BY	SCALE	MATERIAL
			CHK'D	DATE	DRAWING NO.
			TRACED	APP'D	

Fig. A7



## NOTES:

1.  $\odot$  SOLDER TERMINAL ON BOARD
2.  $\odot$  PIN ON INTERCONNECTING BOARD
3.  $\odot$  FEMALE PC MOUNT COAXIAL CONNECTOR
4.  $\odot$  CROSS IN MOUNT FEMALE COAXIAL CONNECTOR
5. FOR S101, S102, S103 & ALL WIRING, SEE A11 SCHEMATIC

REVISIONS			BLOCK DIAGRAM - A1...		
NO.	DATE	BY			
1					
2					
3			DRAWN BY	SCALE	MATERIAL
4			CHEK'D	DATE	DRAWING NO.
5			TRACED	APP'D	

Fig. A8

A-14

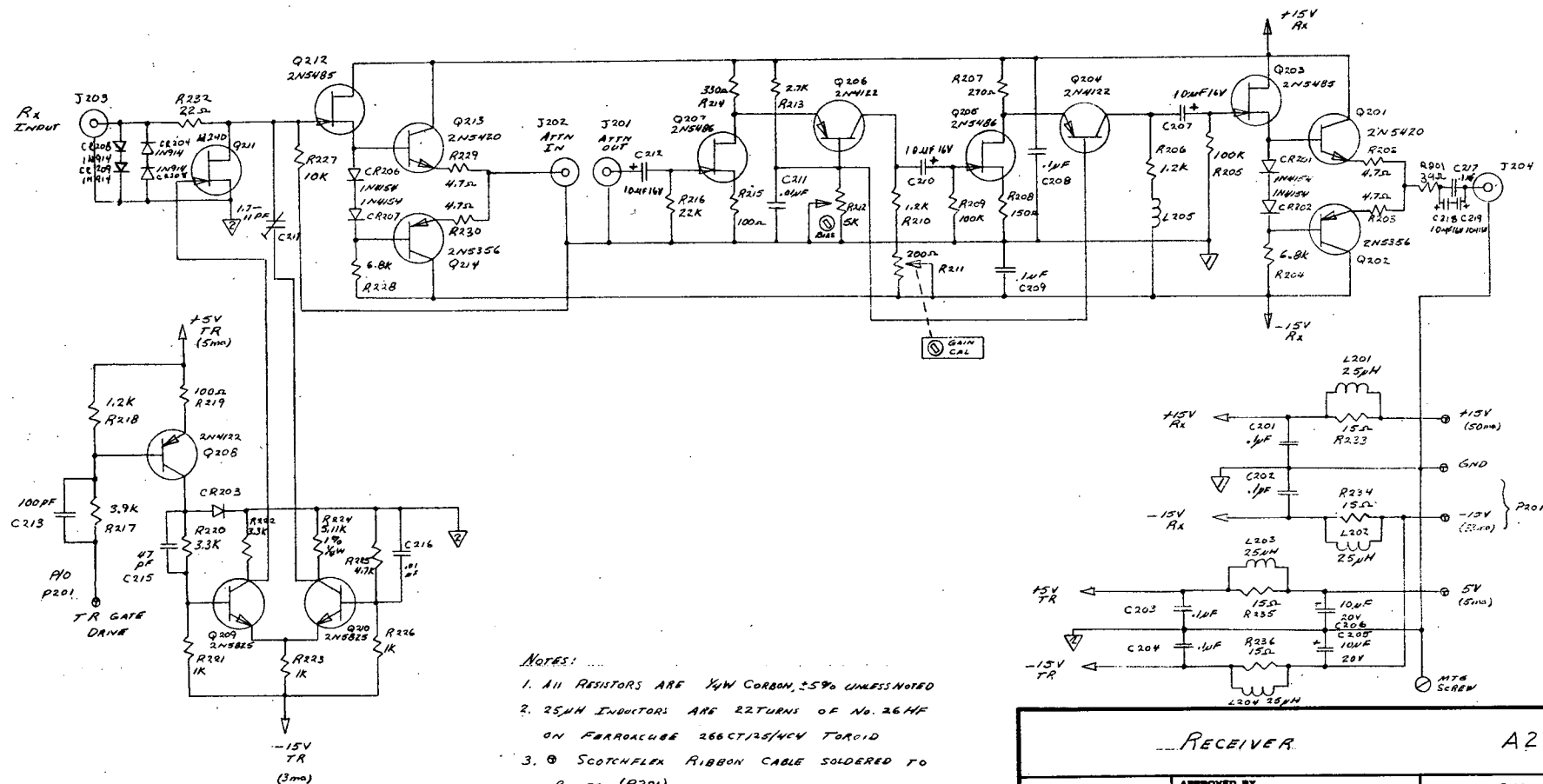


Fig. A9

...RECEIVER			A2
SCALE:	APPROVED BY	DRAWN BY P. KRANEZ	
DATE: 2/10/72		REVISED	
			DRAWING NUMBER

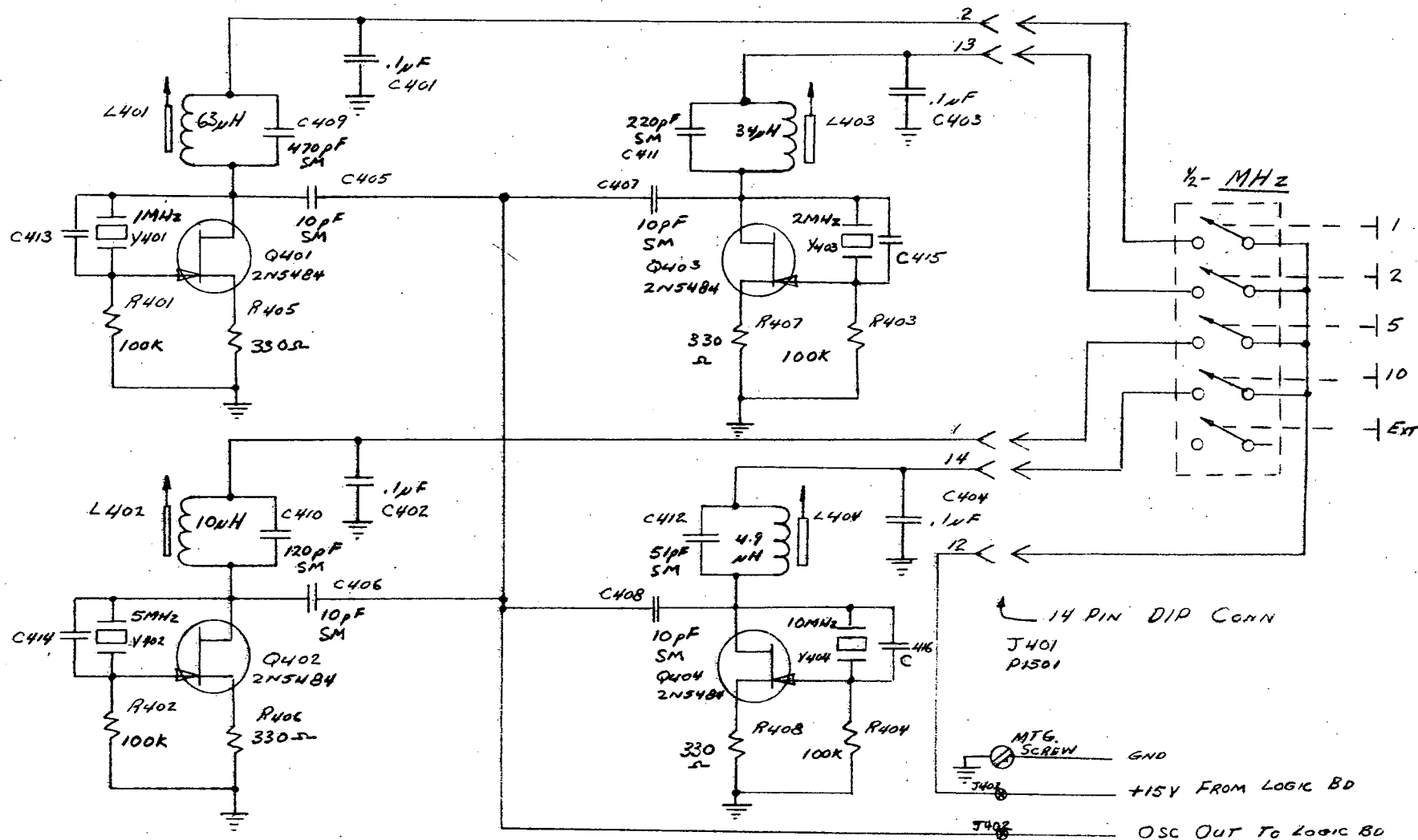
▽ DSI IS PART OF SWITCH ASSY

▽ INDICATES SOLDER TERMINAL  
CABLE TERMINATED IN MICRODOT

ALL RESISTORS ARE IN OHMS  
± 1%, 1/8W, RN55D

Fig. A10.

A-16

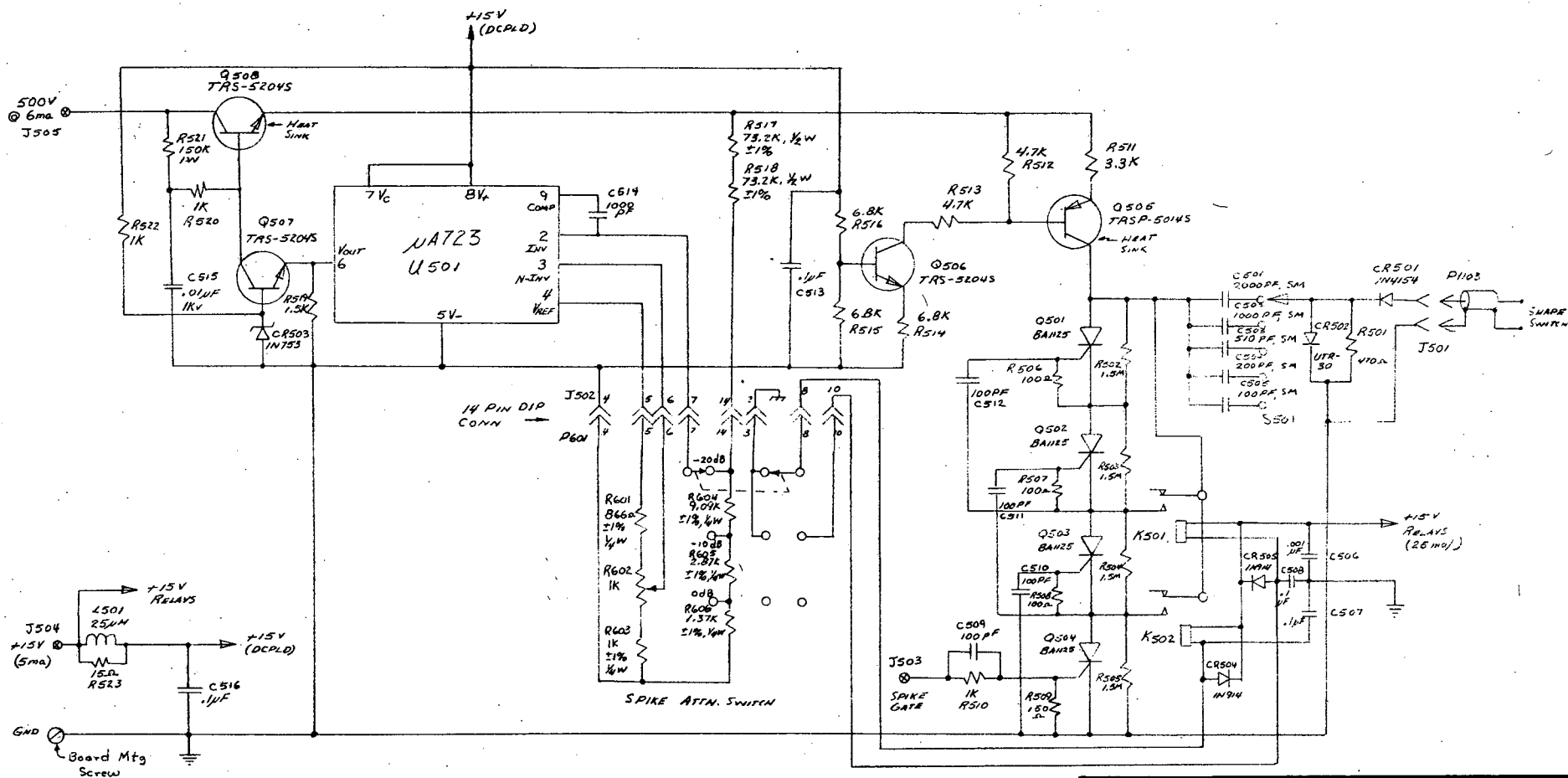


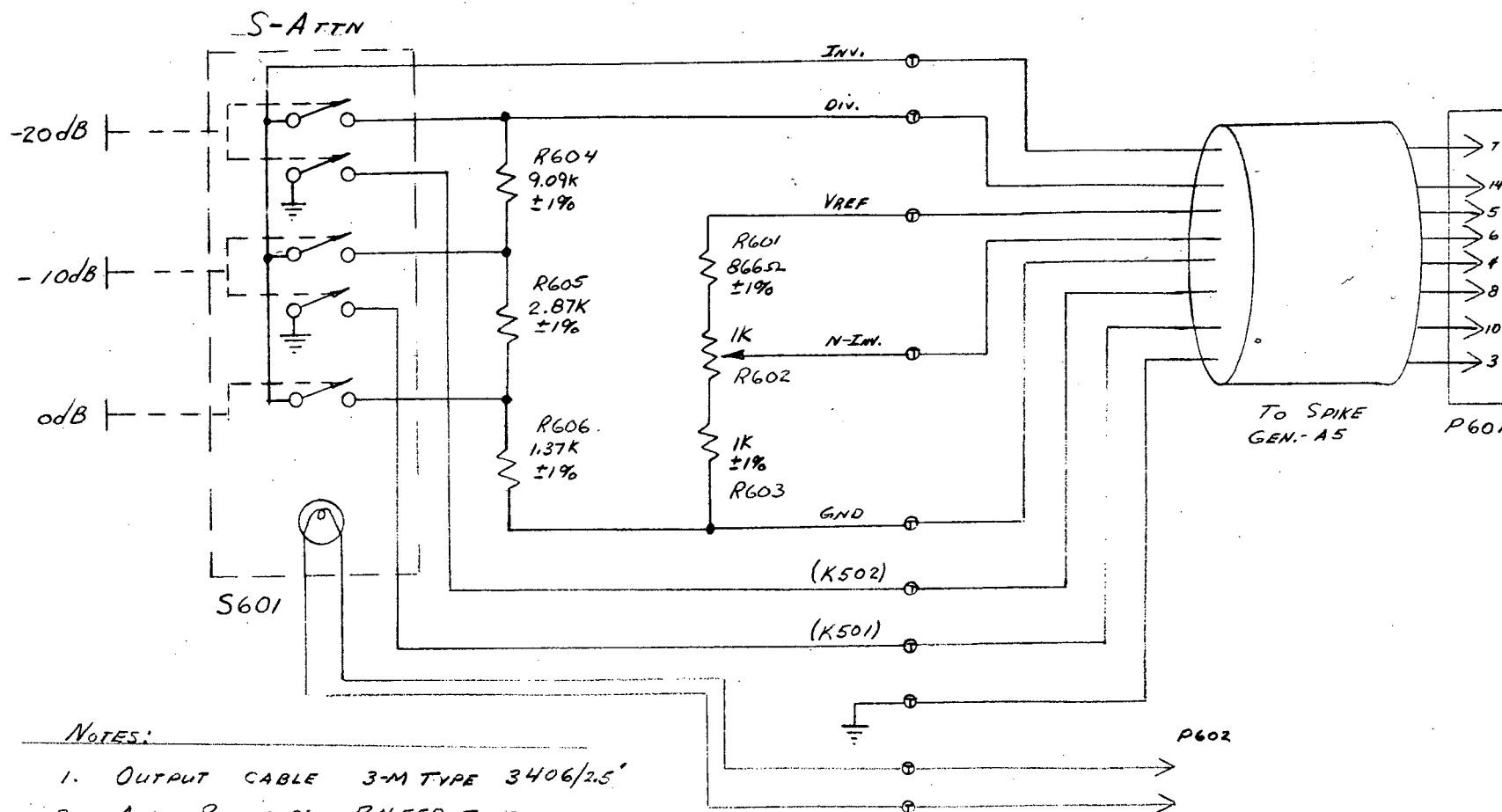
# NOTES:

1. OUTPUT CABLE IS 3M TYPE 360V WITH 14 PIN IC. SOCKET MOUNTED ON OSC BD.
2. 8 PINS TO LOGIC BOARD

REVISIONS			CRYSTAL OSCILLATORS A4		
NO.	DATE	BY			
1					
2					
3			DRAWN BY	SCALE	MATERIAL
4			CHK'D	DATE	DRAWING NO.
5			TRACED	APP'D	

Fig. A11.



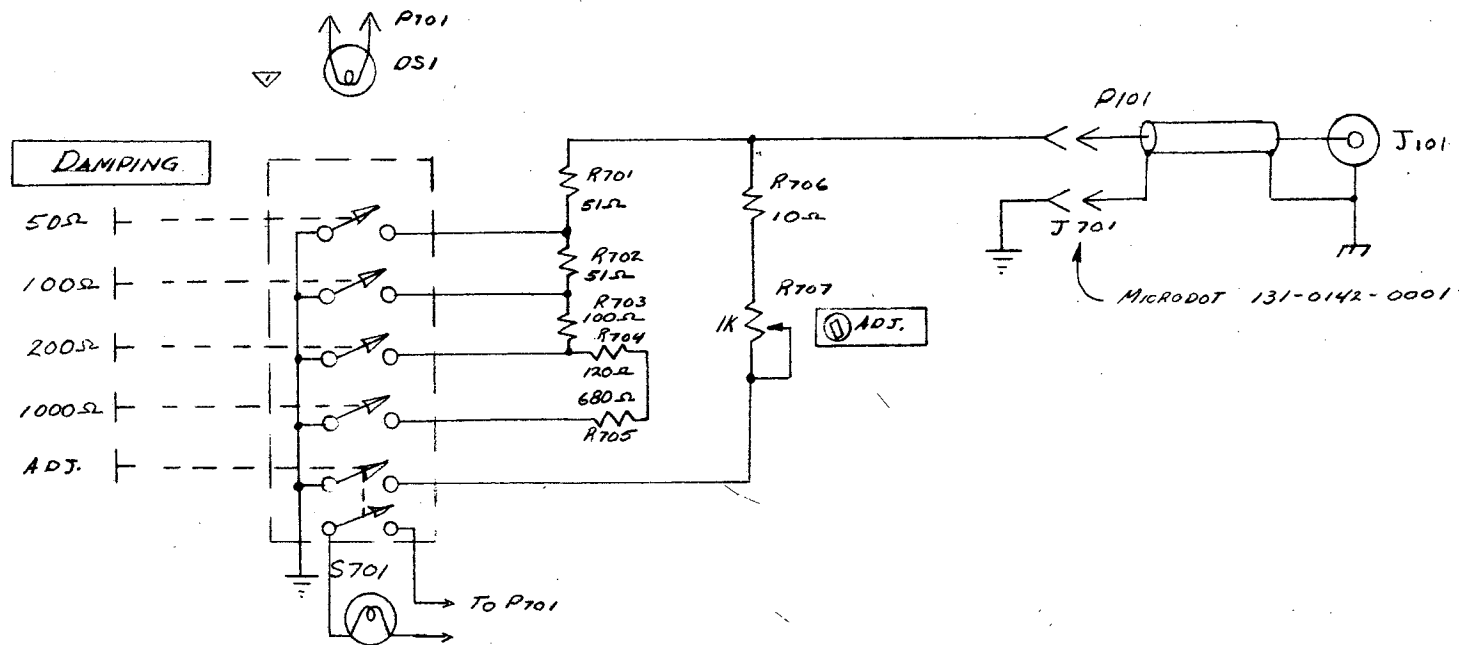


## NOTES:

1. OUTPUT CABLE 3-M TYPE 3406/2.5'
2. ALL RESISTORS RN55D TYPES
3. Ⓢ INDICATES PAD OR SOLDER TERMINAL FOR CONNECTING SCOTCHFLEX CABLE TO BOARD.

REVISIONS			SPIKE GENERATOR ATTENUATOR SWITCH-A6		
NO.	DATE	BY			
1					
2					
3			DRAWN BY P. KRANZ	SCALE	MATERIAL
4			CHK'D	DATE 2/9/72	DRAWING NO.
5			TRACED	APP'D	

Fig. A13



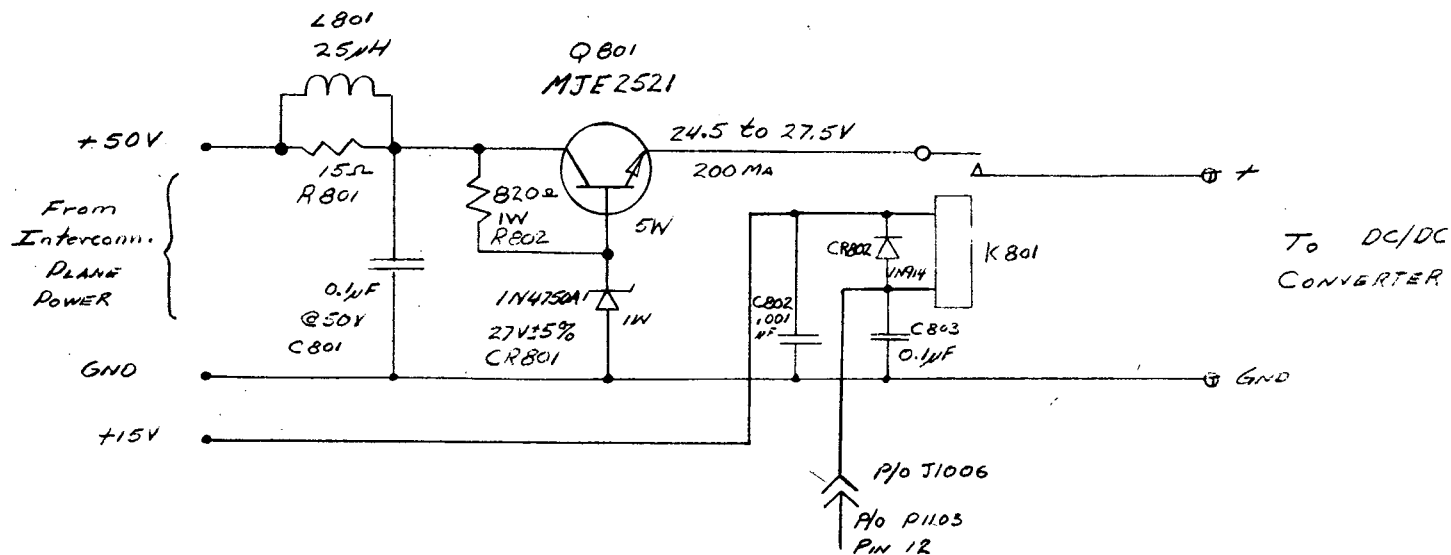
## NOTES

▽ SWITCH ASSEMBLY INCLUDES DSI

REVISIONS			DAMPING SWITCH AT		
NO.	DATE	BY			
1					
2					
3			DRAWN BY P. KRANZ	SCALE	MATERIAL
4			CHK'D	DATE 2/9/72	DRAWING NO.
5			TRACED	APP'D	

Fig. A14



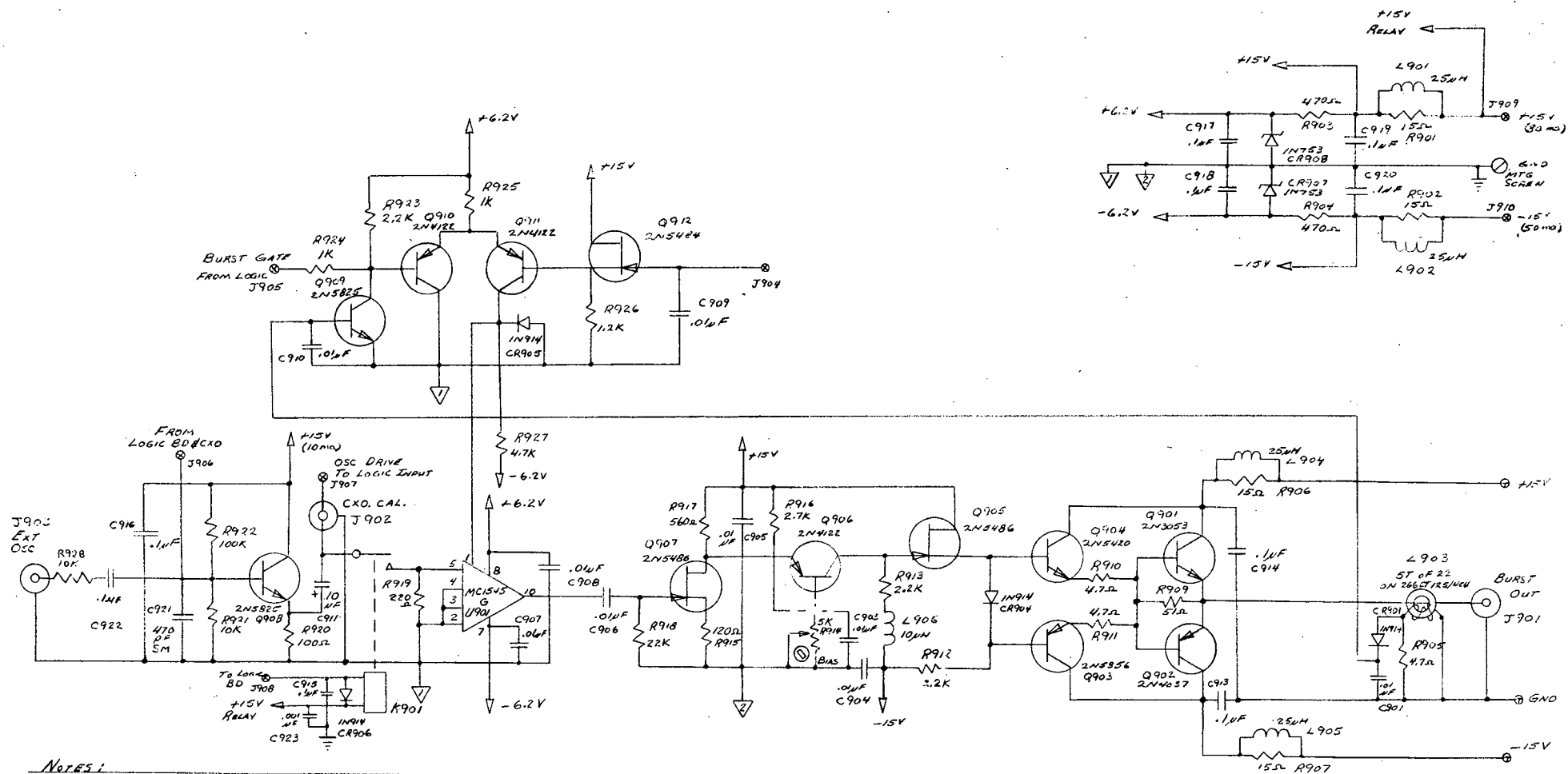


## NOTES:

1. CIRCUIT IS LOCATED ON INTERCONNECTING PLANE
2. Ⓢ SOLDER TERMINAL FOR CONVERTER
3. MJE2521 - HEAT SINK FOR 5W
4. L801-R801: 22 TURNS OF #26 HF ON FERROCUBE 266 CT 125/4C4.

REVISIONS			27 VOLT REGULATOR A8/A16		
NO.	DATE	BY			
1					
2					
3			DRAWN BY P. KRANZ	SCALE	MATERIAL
4			CHK'D	DATE 2/14/72	DRAWING NO.
5			TRACED	APP'D	

Fig. A15



## NOTES:

1. DECOUPLING INDUCTOR: 22 TURNS OF NO 26 HF. ON FERRITECORE 266CT125/4CY.
2. ALL RESISTORS 1/4W CARBON, 15%.
3. O SCOTCHFLEX RIBBON CABLE SOLDERED TO BOARD
4. @ PIN RECEPTAL FROM LOGIC BOARD
5. @ TERMINAL - HIGH CURRENT INPUT
6. COAX CONN IS MICRODOT 131-0143-0001

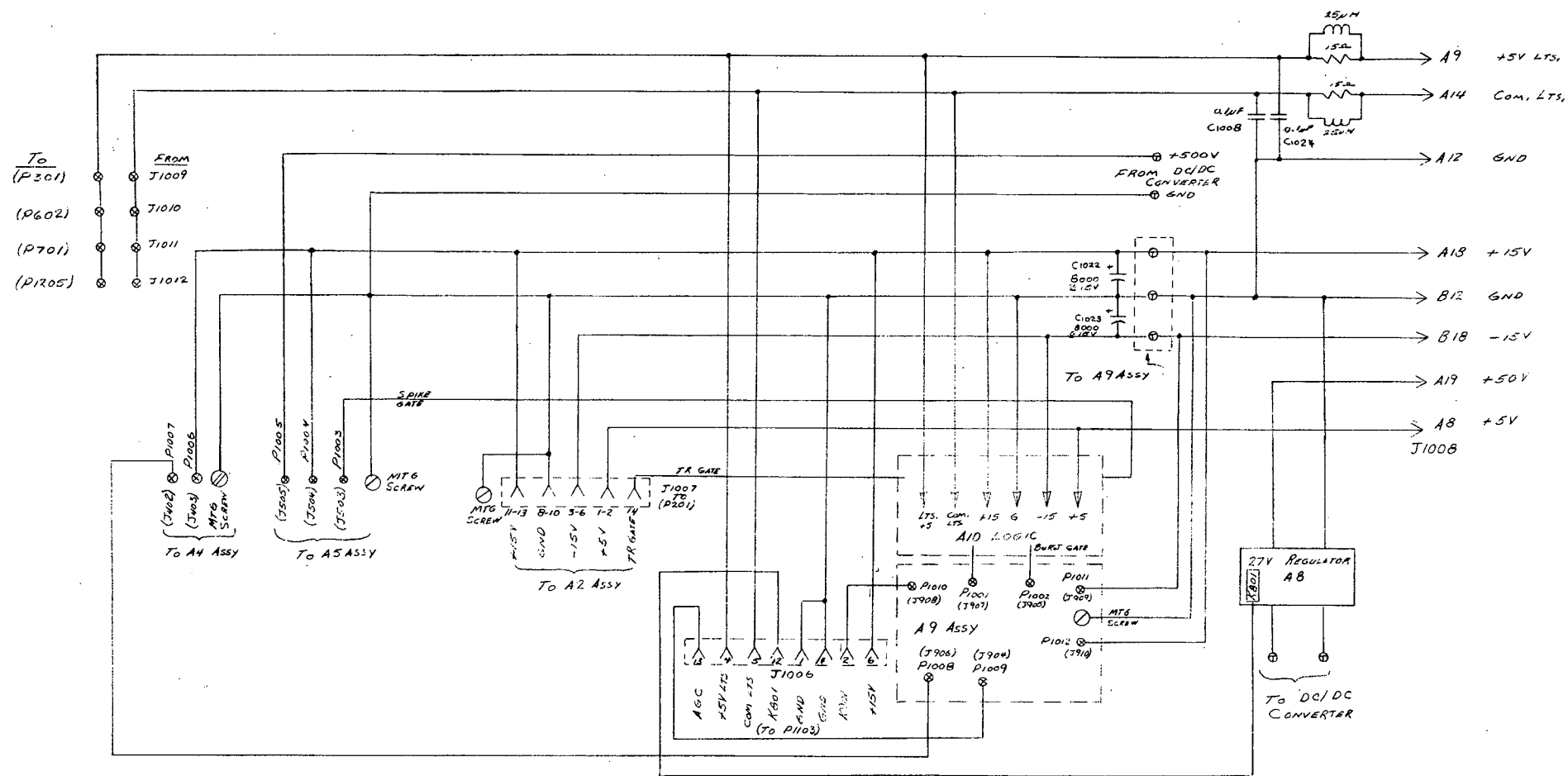
## RF BURST GENERATOR - A9

SCALE:	APPROVED BY	DRAWN BY R. KRANTZ
DATE: 2/10/72		REVISED
		DRAWING NUMBER

Fig. A16

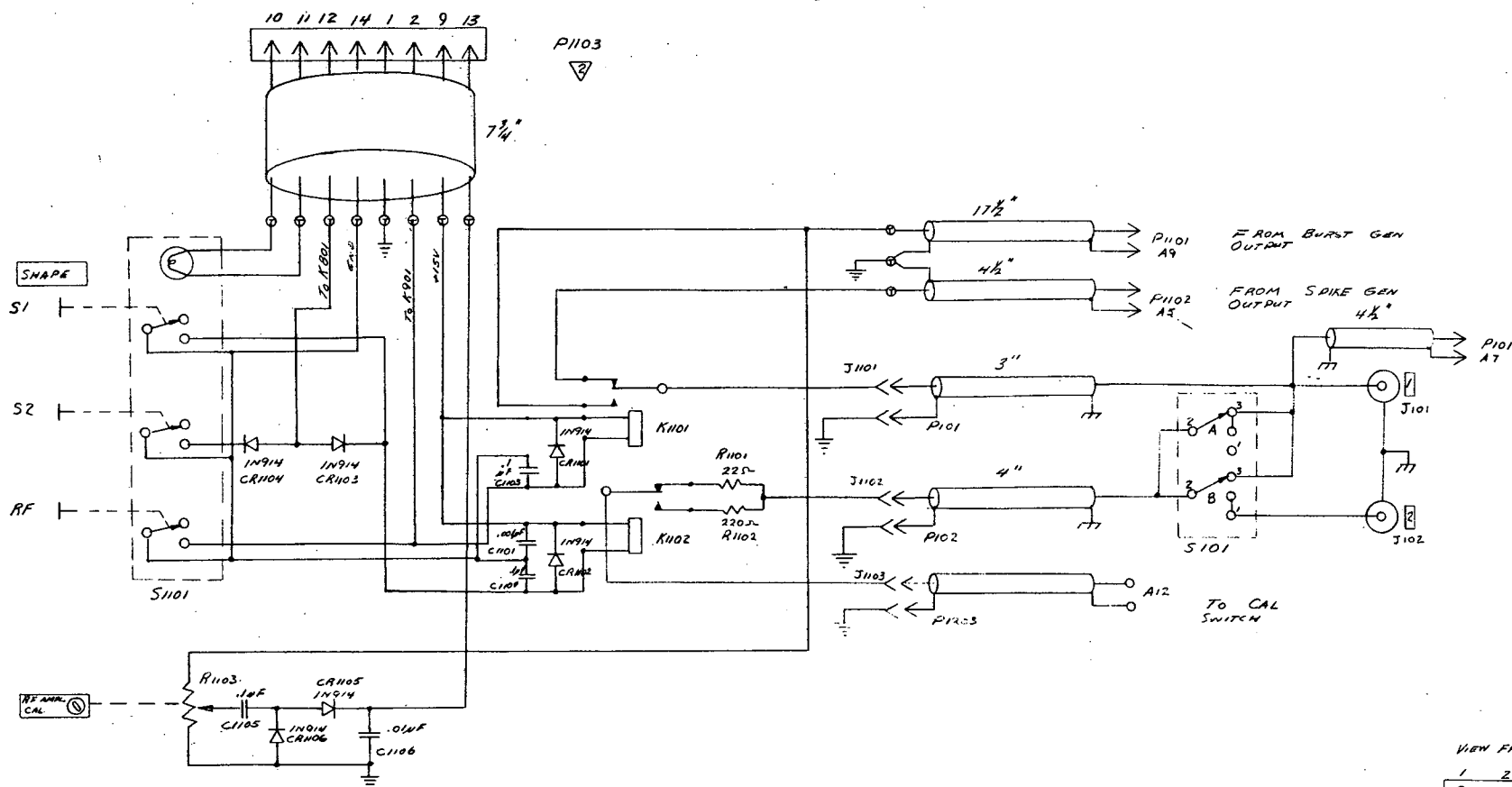


A-2.3



REVISIONS			INTERCONNECTING PLANE A10		
NO.	DATE	BY			
1					
2					
3			DRAWN BY	SCALE	MATERIAL
4			CHK'D	DATE	DRAWING NO.
5			TRACED	APP'D	

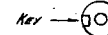
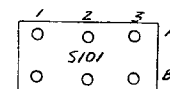
Fig. A18



# NOTES:

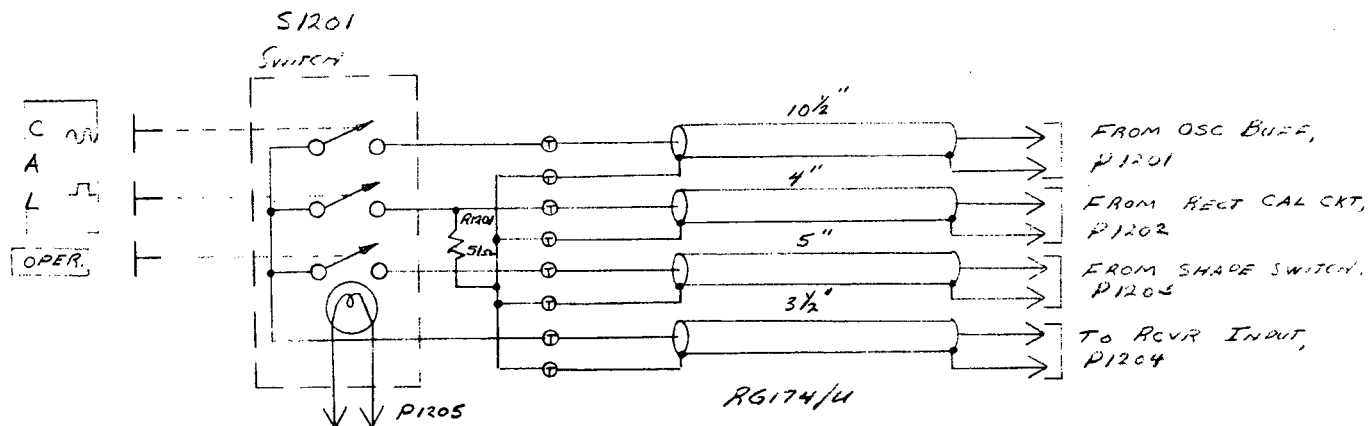
1. S101 SHOWN AS SEEN FROM FRONT
2. 3M-SCOTCHFLEX 3406/2 1/2 ASSEY.
3. Ⓢ SOLDER TERMINAL
4. ALL COAX JACKS ON A11 ARE MICRODOT 131-0142-0001
5. ALL COAX PLUGS ON A11 ARE

VIEW FROM FRONT



REVISIONS			SHAPE SWITCH A11		
NO.	DATE	BY			
1					
2					
3			DRAWN BY	SCALE	MATERIAL
4			CHK'D	DATE	DRAWING NO.
5			TRACED	APP'D	

Fig. A19

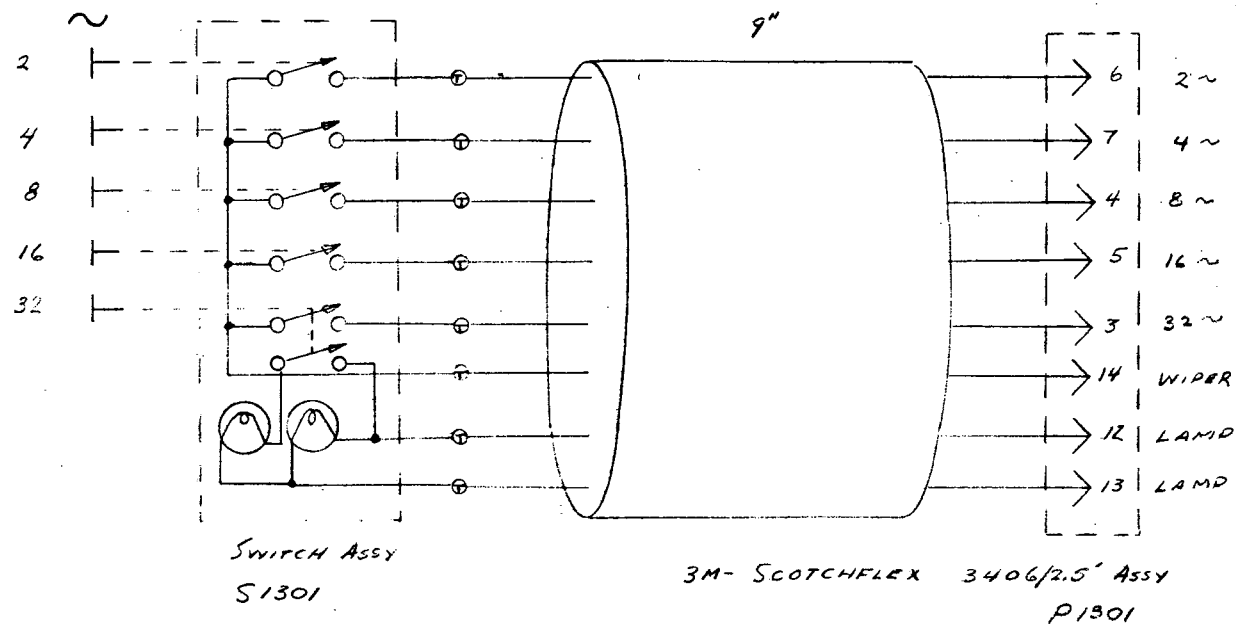


NOTES:

1. ⊕ INDICATES PAD OR TERMINAL FOR COAX SOLDERED TO BOARD

REVISIONS			CALIBRATE / OPERATE SWITCH A12		
NO.	DATE	BY			
1					
2					
3			DRAWN BY P KRAZ	SCALE	MATERIAL
4			CHK'D	DATE 2/16/72	DRAWING NO.
5			TRACED	APP'D	

Fig. A20



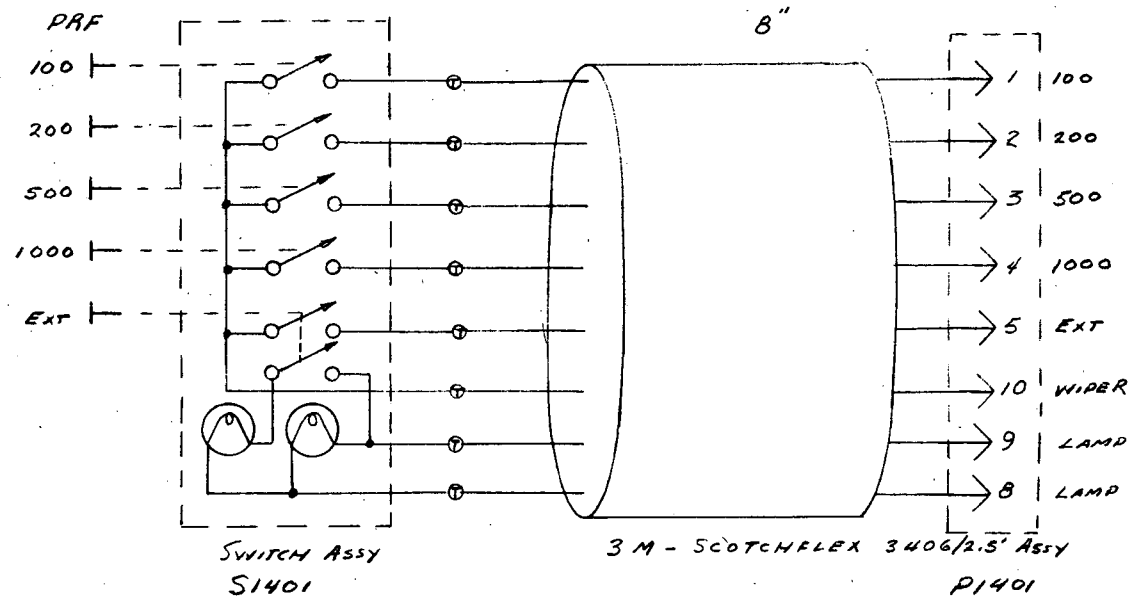
NOTES:

1. Ⓢ PAD OR TERMINAL FOR CONNECTING  
SCOTCHFLEX 3406/2.5' CABLE TO BOARD

REVISIONS			BURST LENGTH SWITCH A13		
NO.	DATE	BY			
1					
2					
3			DRAWN BY PITRANE	SCALE	MATERIAL
4			CHK'D	DATE 2/14/72	DRAWING NO.
5			TRACED	APP'D	

Fig. A 21

A-27



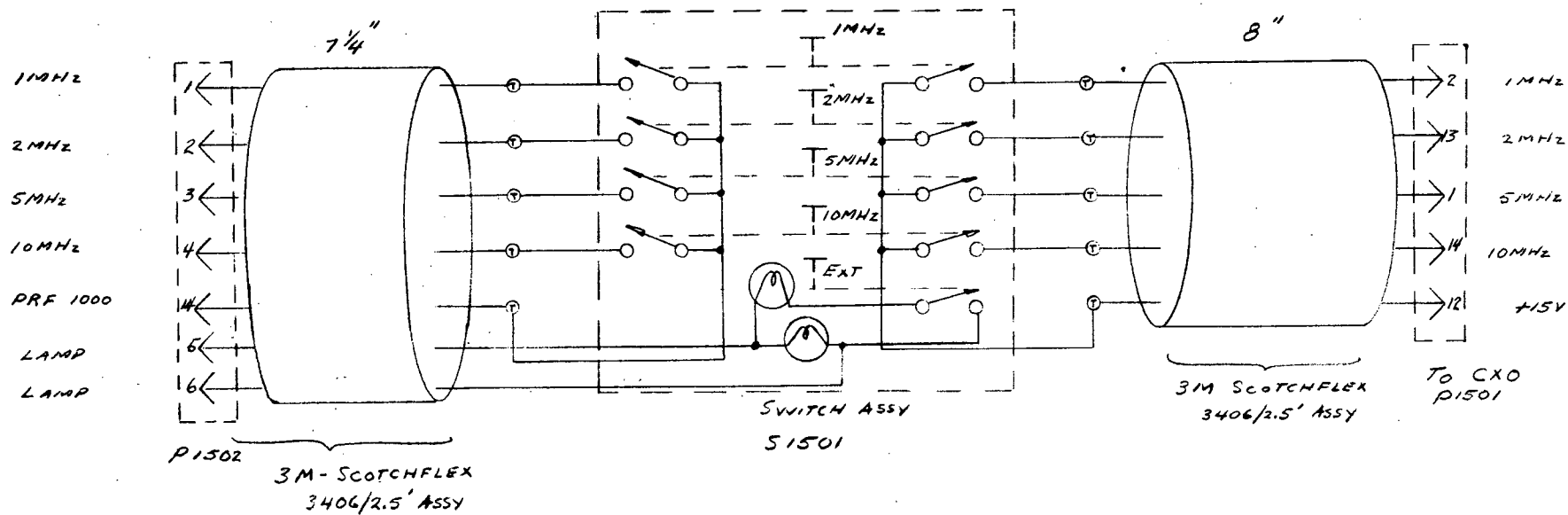
NOTES:

1. @ PAD OR TERMINAL FOR CONNECTING SCOTCHFLEX CABLE TO BOARD

REVISIONS			PRF SWITCH A14		
NO.	DATE	BY			
1					
2					
3			DRAWN BY PKRANZ	SCALE	MATERIAL
4			CHK'D	DATE 2/14/72	DRAWING NO.
5			TRACED	APP'D	

Fig. A 22





## NOTES:

1. Ⓢ PAD OR TERMINAL FOR CONNECTING SCOTCHFLEX CABLE TO BOARD

REVISIONS			MHZ SWITCH A15		
NO.	DATE	BY			
1					
2					
3			DRAWN BY P KRANZ	SCALE	MATERIAL
4			CHK'D	DATE 2/14/72	DRAWING NO.
5			TRACED	APP'D	

Fig. A 23

## APPENDIX B: ATTENUATION MEASUREMENT

Consider a specimen interrogated using a transducer and buffer in pulse-echo fashion, as in Fig. A1. The attenuation coefficient  $\alpha$  and the reflection coefficient  $R$  can be calculated from measurements of the amplitudes of the three echoes A, B and C.<sup>1</sup> In certain cases,  $\alpha$  and  $R$  can be determined without measuring the specimen reverberation echo C.<sup>2</sup>

The above methods have been combined to yield  $V$ ,  $\alpha$  and  $R$  simultaneously.<sup>3</sup> Thus, in what may be termed the "ABC Overlap Method," one measures, in a specimen of length  $L$ , the three amplitudes A, B and C, and the period  $T$  (or overlap frequency  $F = 1/T$ ). All the necessary ultrasonic data - A, B, C and  $F$  - are contained in a single oscillogram as in Fig. A3.

When A, B and C are normalized by dividing by B to give  $\bar{A} = A/B$  and  $\bar{C} = C/B$ , the sound pressure reflection coefficient  $R$  and attenuation coefficient  $\alpha$  may be obtained from the nomogram, Fig. B1, or from the equations:

$$R = -[\bar{A} \bar{C} / (1 + \bar{A} \bar{C})]^{1/2} \quad (B1)$$

and

$$\alpha = [\ln \bar{A} - \ln \bar{C} - \ln (1 + \bar{A} \bar{C})] / 4L. \quad (B2)$$

For cases where  $\alpha$  is so large that C cannot be measured accurately (i. e., errors in C exceed a few percent), one obtains  $\alpha$  and  $R$  by the "AB Overlap Method," measuring A and B and either  $A_0$ , the interface echo with the specimen uncoupled, or  $A'$ , the buffer rod's reverberation echo. Here, if  $A_0$  is measured,  $R = -A/A_0$ . If  $A'$  is measured,  $R = -A'/A$  (beam spread, mode conversion, transducer losses, electroacoustic non-linearity neglected). In terms of  $R$ , A and B:

$$\alpha = (1/2L) \ln [ (A/B) (R^2 - 1)/R ]. \quad (B3)$$

For routine determinations of  $R$  and  $\alpha$  one may utilize an accessory instrument or calculator programmed in terms of peak-detected signals A, B and C. This function can be combined with a suitable Signal Processor (Appendix E).

The particular design features in the 5051 that relate to these measurements, are linearity and wide dynamic range. Since these same features are found in the 7A12, the complete system is capable of measuring

$\alpha$  and R with errors typically in the range 1 to 10%. Since  $\alpha$  may range over several orders of magnitude, depending on the material and test frequency, such errors will usually be tolerable.

#### References

1. E. P. Papadakis, J. Appl. Phys. 42 (7), 2990-2995 (June 1971).
2. L. C. Lynnworth, Materials Evaluation 29 (2), 27A (Feb. 1971).
3. E. P. Papadakis, K. A. Fowler and L. C. Lynnworth, ONR Progress Report for Quarter Ending November 15, 1970, Contract N00014-71-C-0050.

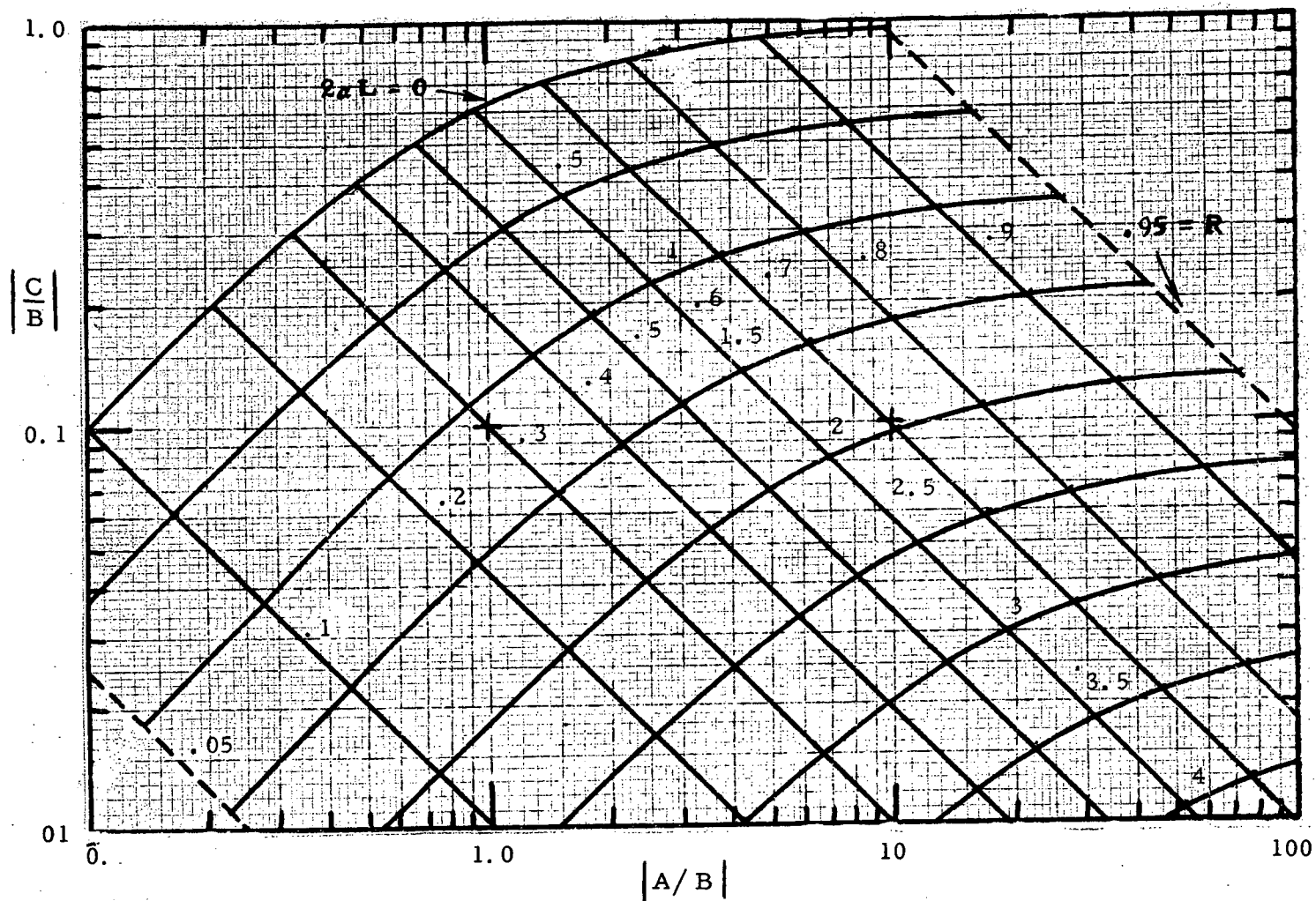


Fig. B1. Nomogram of propagation loss  $2\alpha L$  and reflection coefficient  $R$  as a function of echo amplitudes normalized with respect to echo  $B$  in an experiment utilizing a specimen on the end of a buffer rod or lead-in wire.

## APPENDIX C: CABLE EFFECTS

As the center frequency and bandwidth of pulsed transducers are raised above 5 MHz, the effects of the coaxial cable on overall system performance can no longer be neglected. A brief study of these effects was conducted to examine under what conditions they might possibly affect system performance.

The results were separated into effects on the transmitted pulse waveform and effects on the received echo. Theory showed, and experiments confirmed, that in transmitting a pulse to the transducer from typical pulser circuitry such as is used in this contract, the cable causes a 6 dB/octave or greater attenuation of pulse components above a characteristic frequency  $f_c$ . For a typical 5 MHz transducer (VIP-5-1/2-C)  $f_c = 10$  MHz and for a typical 10 MHz transducer (VIP-10-1/2-C)  $f_c = 5$  MHz. There are minor "ripples" in the attenuation above  $f_c$ .

The effect of the cable on echo reception is to provide a peak in the frequency response in the region between 10 MHz and 40 MHz for typical transducers. Peak amplitude can be as high as 15 dB if the receiver damping resistance is above 50 ohms. If the receiver damping resistance is less than 50 ohms, attenuation with sharp dips and peaks results above 10 MHz. These effects can cause the received echo to "ring" at an apparent frequency between 10 MHz and 40 MHz when the receiver damping resistance is other than 50 ohms.

These points may be elaborated on as follows (see also Figs. C1-4): A typical 5 foot length of RG174/U cable has a two way transmission delay of 15.4 ns. In intervals less than several times greater than this, the transducer is effectively driven from and drives into a 50 ohm resistor. For times greater than about 50 ns, the source and load impedances of the pulser-receiver are the important quantities. For a typical transducer capacitance of 1000 pf, the fastest rise (or fall) in voltage which can be achieved across the transducer is about 30 ns. This limit arises because the initial 50 ohm source impedance from the cable causes a very slow rise time (50 ns to 63%) and at least 2 reflections from the source are required to charge the transducer. Even the 30 ns charge time will not be achieved, however, unless the pulser source impedance is less than 10 ohms. Therefore, excitation rise times of less than about 30 ns and efficient excitation above 10 MHz cannot in general be achieved with capacitive transducers at the end of cables several feet long. It is important to realize that these conditions and limitations arise because of the cable and the capacitive nature of the load, not because of the pulser. It would be misleading to specify pulsers for these transducers in terms

of a resistive load. Performance specified in this way will deteriorate when a cable and transducer are connected. However, since the damping resistance does appear in shunt with the cable, the specification should include the value of the damping resistance chosen along with a description of the cable and transducer used.

For similar reasons, the receiving response characteristic of this transducer-cable-amplifier system shows strong spectrum distortion (peaks and valleys) above 10 MHz if the receiver input resistance (usually called damping) is other than 50 ohms. This is a consequence of placing cable between the transducer and receiver. Independent choice of damping resistor is not possible if a flat spectrum response is desired. These effects can be eliminated by placing the pulsing and first receiving circuits in close proximity to the transducer. Spacing of a few cm or less ( $\sim 1''$ ) would be appropriate for use up to 100 MHz.

In summary, for broadband transducers and spike excitation, cable effects are increasingly important above  $\sim 10$  MHz. (For rf burst excitation cable effects are to be considered even below 10 MHz - see Appendix H.)

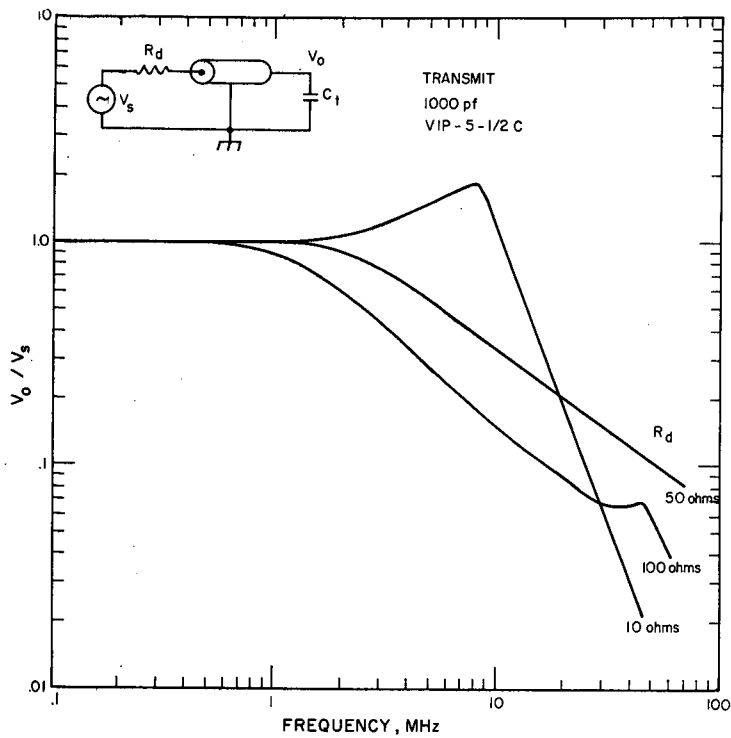


Fig. C1.

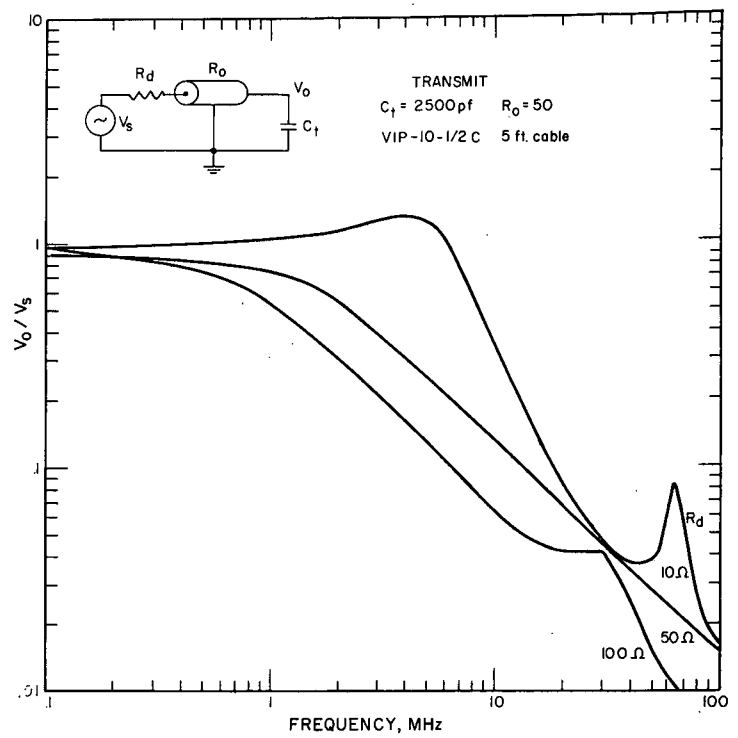


Fig. C2.

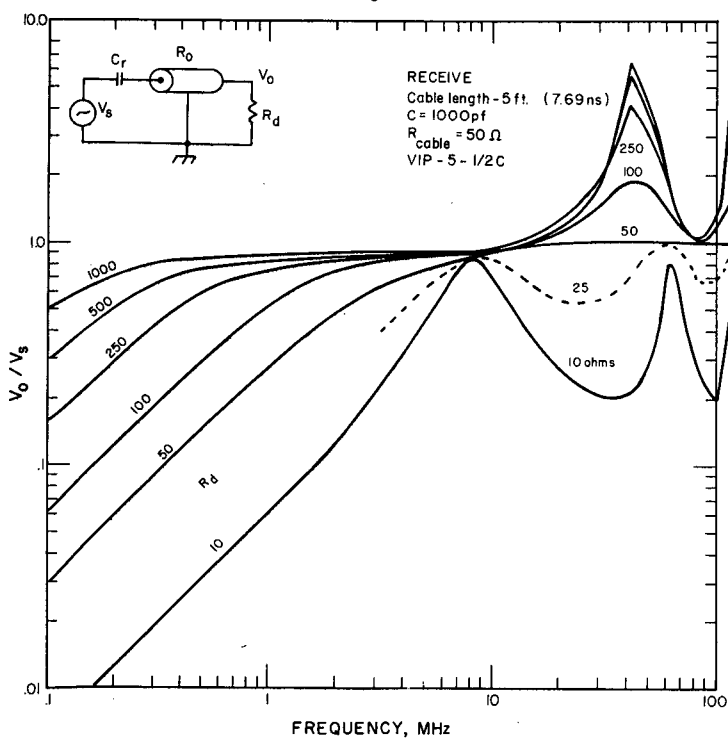


Fig. C3.

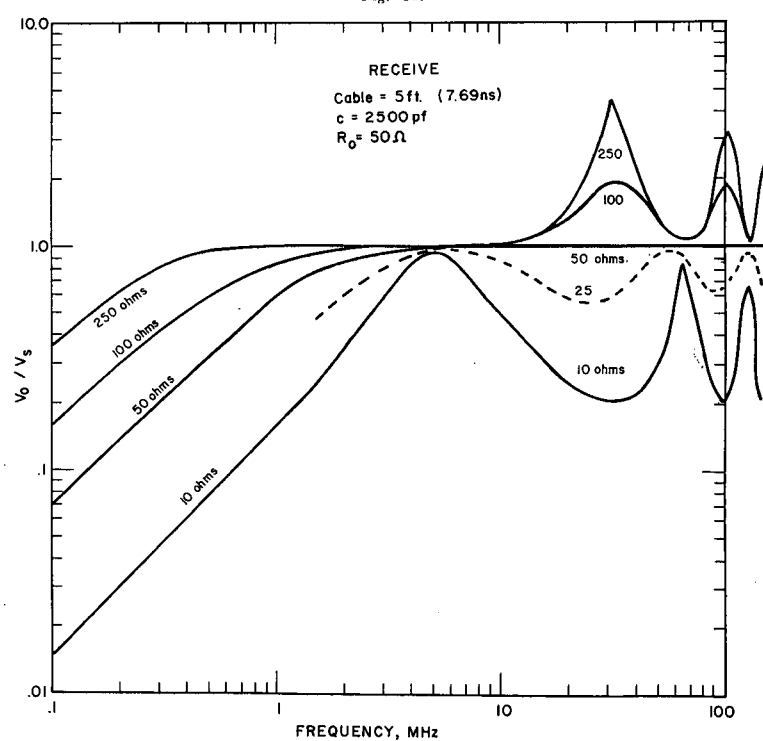


Fig. C4.

## APPENDIX D: TRANSITION TIMES

Pulse Shape. The pulse shape that potentially could yield the highest resolution is the step, or single transition to ground. With a broadband transducer one can theoretically achieve, in the very near field, a half-cycle, unipolar echo with bandwidth well in excess of 100%. This pulse shape would normally be desired for defect detection and analysis, particularly in thin sections, or for defect searches close to an interface.

The transition time  $t_r$  for a step determines the open circuit electrical bandwidth:  $BW = 1/2 t_r$ . In practice, the bandwidth is limited by the cable, transducer, and ultimately, by coupling and attenuation in the test material. The amplitude of the step determines the electrical pulse strength.

(When comparing broadband vs narrow band systems, it is to be understood that, when a given piezoelectric material is critically damped (perfectly terminated acoustically) its vibration amplitude cannot be as large as if it were only partly damped. Similarly, broadband electronics admits more electrical noise than narrow band (tuned) electronics. Random noise increases in proportion to the square root of bandwidth.)

The step pulse shape may ultimately be preferred for bond evaluation since its unipolar character will lead to simpler echo polarity identification, augmenting pulse amplitude and spectral information.

Ultrasonic spectroscopy also would be enhanced by the step pulse, in some cases, because of the large bandwidth.

Experiments on the effect of step transition times, pulse width and damping were conducted initially using a Hewlett-Packard variable transition time output model 1915A as the pulser. (This instrument provides up to  $\pm 50V$  open circuit, with pulse top variations of  $\pm 2$  to  $\pm 5\%$ , depending on the transition time.) Theory and experiments illustrated in Figs. D1-5 show that a single transition yields the echo of highest resolution, but a rectangular pulse (double transition) can yield higher amplitude.

During Phases I and II it was understood that driving voltages considerably greater than 50V would be desirable. Therefore, experiments were conducted on breadboard circuits for producing a single transition to ground. Unfortunately several difficulties were encountered. A first limitation arose from the cable (see Appendix C). A second limitation arose from transient effects associated with switching off in a few ns, a



voltage source of several hundred volts (slewing rate  $\sim 10^{11}$  V/s). Thirdly, it was observed that the ideal echo singlet or doublet shapes quickly deteriorated for nonelectrical reasons, as the pulse propagated a few mm. That is to say, the observed difference in pulse shape, when comparing a step to ground vs the more usual spike excitation, was generally not significant. Results did not appear to justify the substantial effort anticipated, if one desired to produce a high-voltage step to ground, using presently available solid state switches.

To avoid these difficulties within the framework of this program, we chose a more conventional route, and explored "spike" excitations S1 and S2 with exponential return to ground governed by two different time constants.

In the first waveform, S1, the recovery time is dependent upon the product of the coupling capacitor,  $C_c$ , and the damping resistance,  $R$ , chosen by the operator. In the second waveform, S2, the recovery time is dependent upon the product of the coupling capacitor and a fixed resistance of 50 ohms.

The damping resistance thus affects both the excitation and echo in the S1 case but affects only the echo in the S2 case (see Fig. 10).

When the damping resistance chosen is other than 50 ohms, the S2 waveform will provide a flatter baseline than will the S1 waveform. However, this faster baseline recovery is at the expense of a loss in echo amplitude.

Receiver Recovery Time. The receiver recovery problem consists of three main parts: (a) Transducer discharge, (b) Noise injected by pulser, and (c) Receiver overload (saturation).

(a) The transducer discharge rate is normally governed by an RC time constant where  $C$  = capacitance and  $R$  = damping resistance. The exponential decay follows the equation  $V = V_0 e^{-t/\tau}$  from which it is readily seen that the voltage discharges by one order of magnitude per 2.3 time constants ( $\ln 10 = 2.3$ ). Thus to discharge from 100V to 10V takes  $2.3\tau$ , and from 100V to 10  $\mu$ V takes  $16.1\tau$ .

If we assume  $C = 2000$  pf, the effect of damping resistance on recovery time from 100V down to 10  $\mu$ V is as follows:

<u>R, OHMS</u>	<u>TIME CONSTANT, ns</u>	<u>RECOVERY TIME, <math>\mu</math>s</u>
500	1000	16.1
50	100	1.61
5	10	.161

Using a small coupling capacitor, to reduce  $C$ , speeds the recovery at the expense of drive amplitude.

The other approach, to lower the circuit parallel resistance, is potentially a good solution if it is done over the proper time interval. A permanently low resistance is unwise because it will require high pulse power and provide an unsatisfactory receiving termination.

Therefore switching of a low resistance across the line during the recovery period after the main bang is attractive. Such a switching circuit must itself inject a low level of noise into the receiver during the recovery period or else have a suitably short noise recovery time of its own. In practice it is this requirement which may ultimately place a limit on recovery time.

(b) The pulser itself must inject no noise above the specified receiver noise level into the receiver near and past the end of the recovery period. This requirement is progressively more difficult to meet as the recovery time is shortened below 500 ns. Some avalanche transistors, for example, exhibit "noise" in the millivolt region up to 200 ns after avalanche due to charge redistribution effects in the transistor. Other fast rise pulse sources may exhibit similar noise.

(c) Third, the receiver electronics must recover from overload or gain reduction sufficiently fast to meet the desired recovery time. This is not as severe as the previous two problems but becomes difficult below about 100 ns. Receiver overload recovery becomes more of a problem as gain is increased but may be avoided by lowering clipping levels at the receiver input.

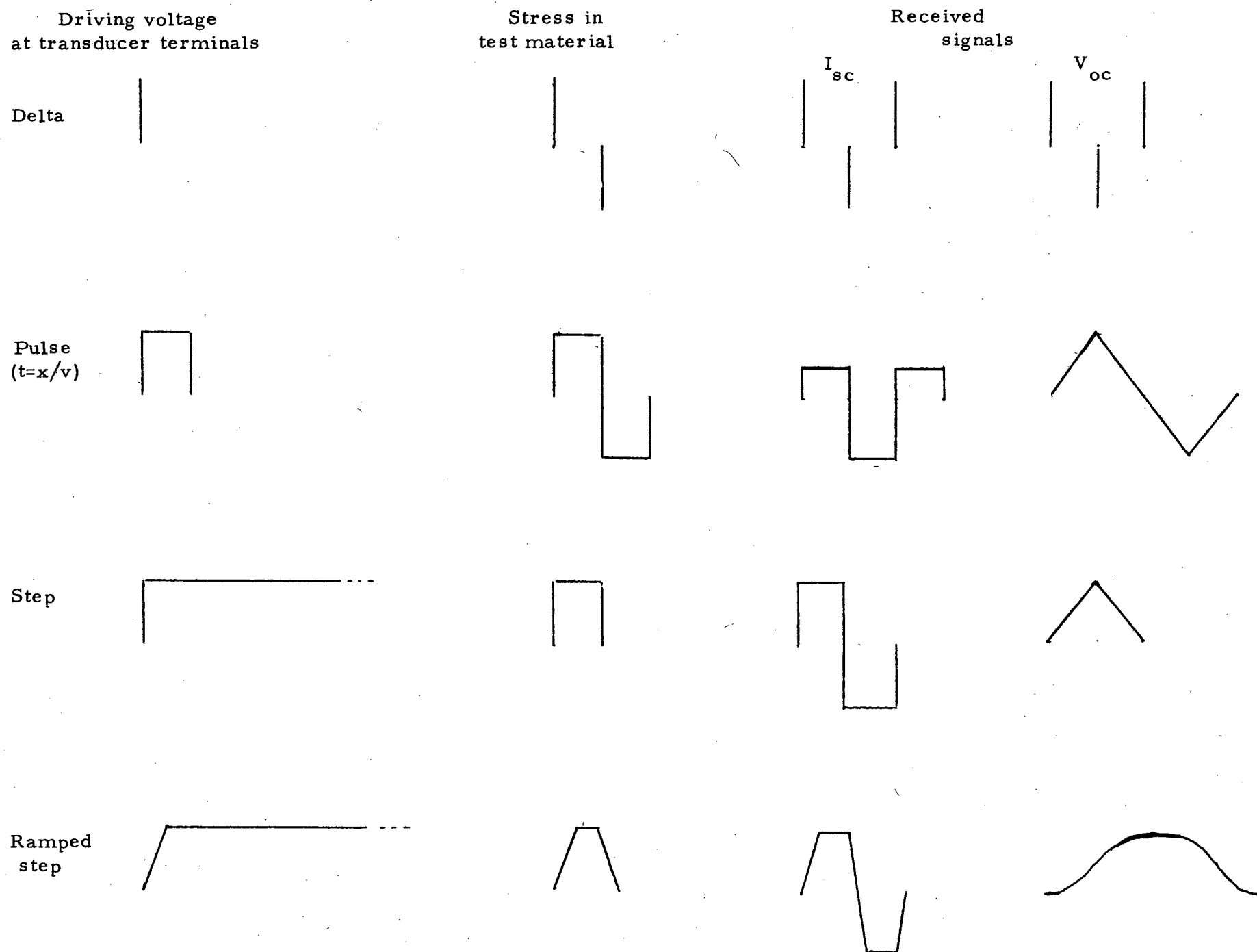
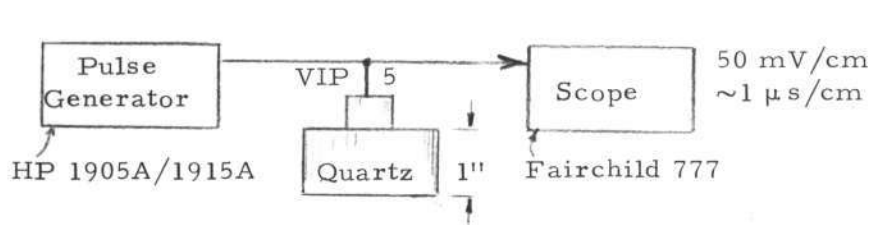
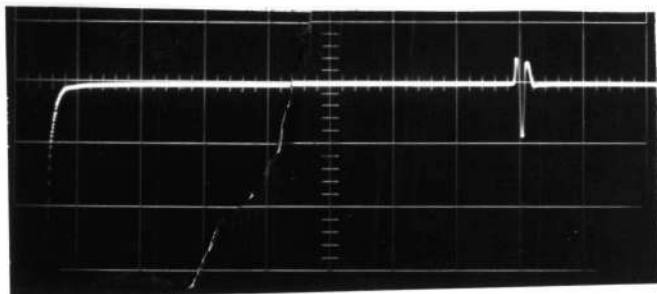


Fig. D-1. Idealized waveforms for acoustically matched transducer. (Transducer thickness =  $x$ , velocity =  $v$ .)

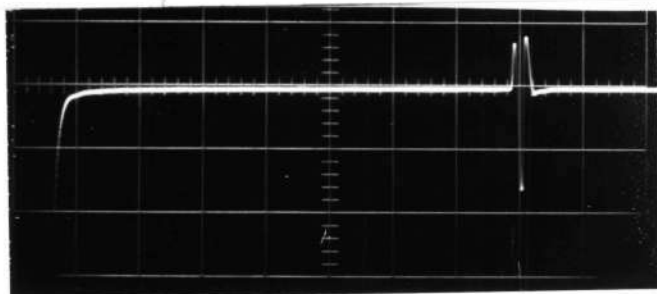


#### Experimental Conditions:

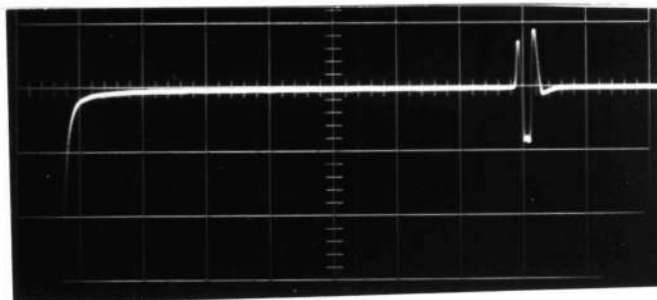
Transition times minimum;  
50 $\Omega$  source impedance; VIP-5  
broadband transducer in con-  
tact with 1" thick block of  
fused silica - "quartz"



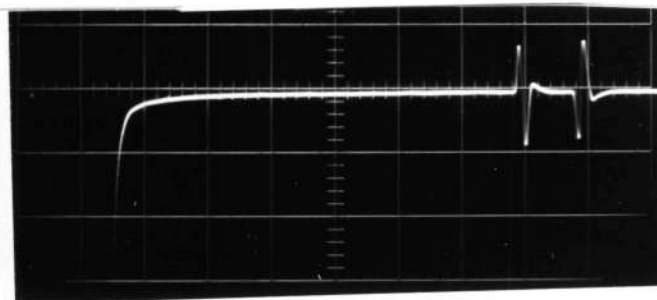
- (a) Pulse width = 40 ns (less than optimum)  
Echo amplitude = 45 mV



- (b) Pulse width = 100 ns (optimum)  
Echo amplitude = 80 mV; this is a  
time domain maximum value;  
note symmetry of video triplet  
echo shape.



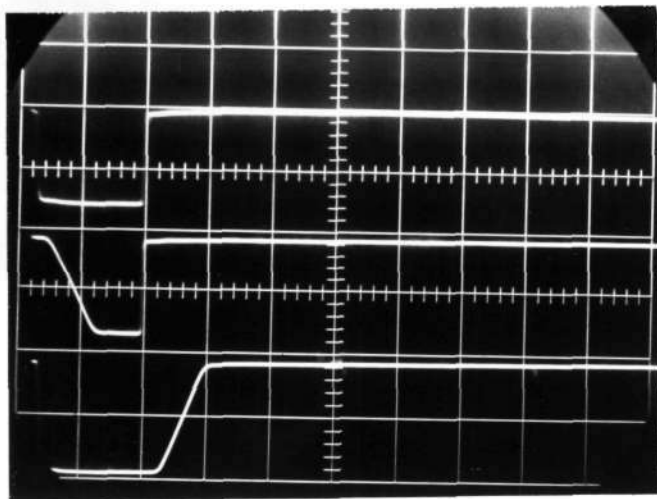
- (c) Pulse width = 200 ns (greater than  
optimum)  
Echo amplitude = 40 mV; echo  
distorted, starting to split into  
echo pair.



- (d) Pulse width = 1000 ns = 1  $\mu$ s (much  
greater than  
"optimum")  
Echo amplitude = +40 mV; echo pair  
now separated by interval equal to  
pulse width. At expense of amplitude  
in the time domain, each echo has  
gained bandwidth in the frequency  
domain, i. e., greater information  
content.

Fig. D-2. Effect of rectangular pulse width on echo shape.

Experimental Conditions: same as previous figure, except pulse width = constant for each oscillogram.



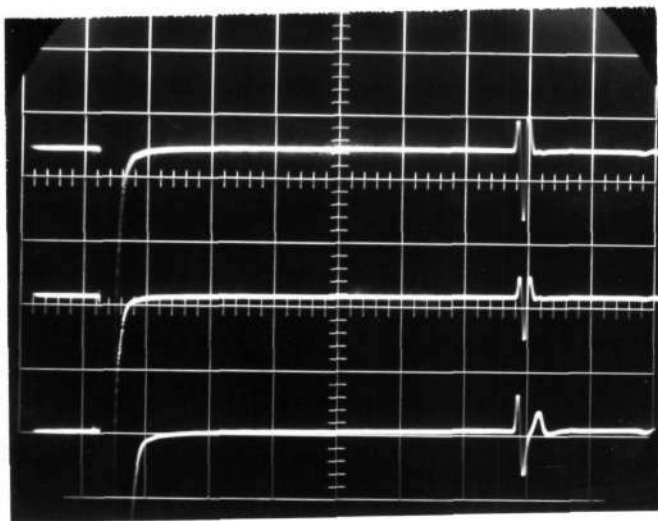
Illustrative output waveforms of pulse generator unloaded by transducer:

Rise time = fall time = minimum

Rise time = 50% of pulse width

Fall time = 50% of original pulse width

(Rise time relates to leading edge:  
Fall time relates to trailing edge.)



Symmetrical echo obtained using rectangular 100 ns pulse width:

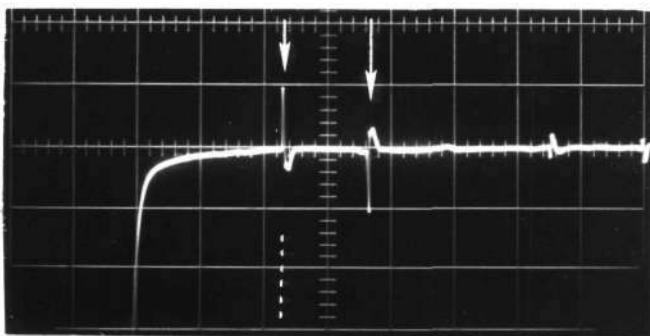
Rise time = Fall time = minimum  
(~3 ns)

{ Fall time = minimum;  
Rise time increased. Echo amplitude decreases. Distortion not apparent.

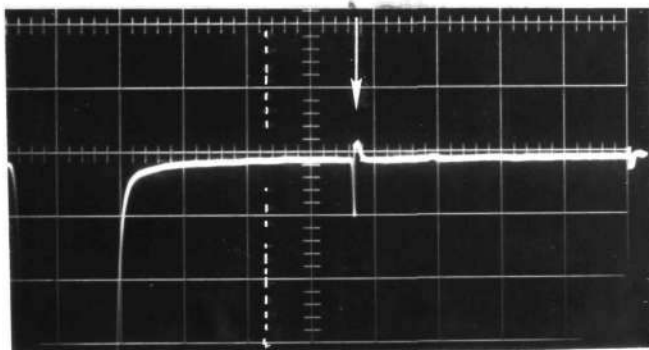
{ Rise time = minimum;  
Fall time increased. Echo amplitude decreases. Distortion apparent.

Conclusion: optimum symmetrical video triplet echo is obtained with a rectangular pulse having a width equal to half the period of the transducer's nominal upper frequency. (VIP-5 operates at a center frequency of 5 MHz. Period = 200 ns. Optimum pulse width = 100 ns.)

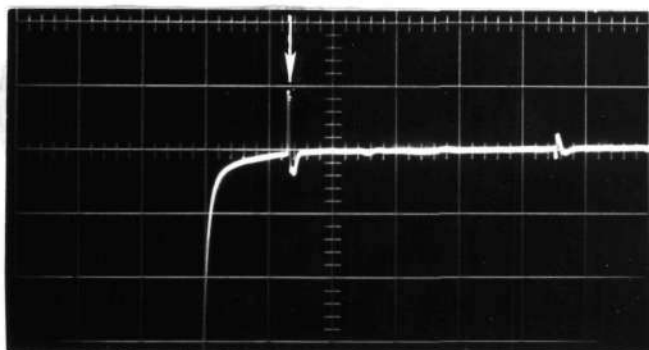
Fig. D-3. Effect of transition times on echo shape.



- a. Both leading and trailing edges set for minimum transition times. Each edge generates an echo. Reverberation of the echo pair in the 1" quartz block is also seen.



- b. Leading edge ramped until first echo in echo pair disappears. The only echo generated is due to sharp trailing edge. Compare echo and its reverberation with above oscillogram.



- c. Trailing edge ramped, leading edge sharp. Converse of case b above. Compare with a and b.

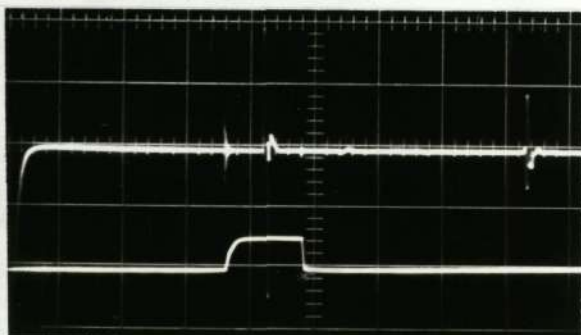
2  $\mu$ s/cm

50 mV/cm

Specimen: 1" quartz block

Fig. D-4. Effect of transition time when width of "rectangular" pulse  $\approx 3\mu$ s >> half-period of VIP-10.

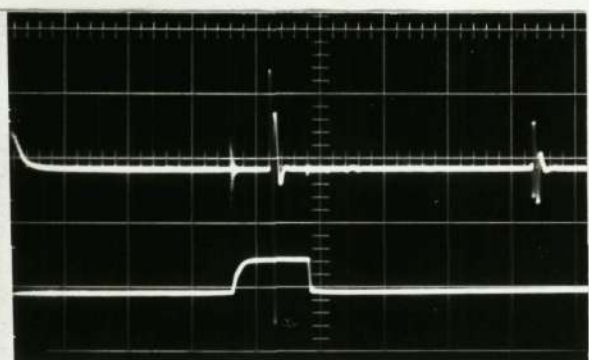
TIME  
DOMAIN



$R_p = 45\Omega$



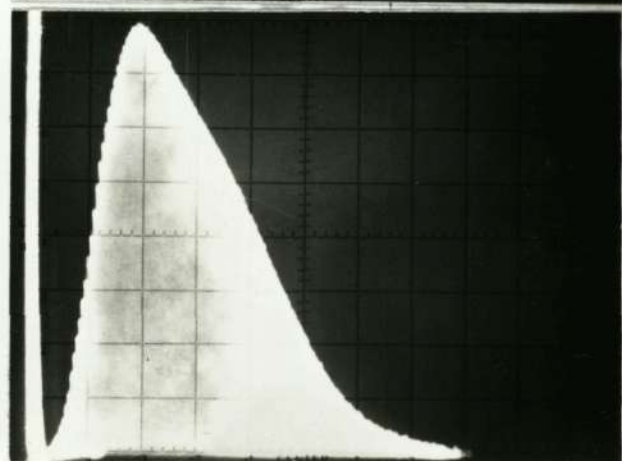
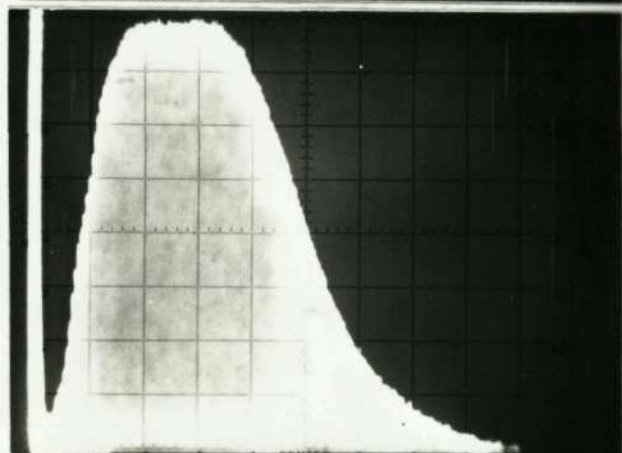
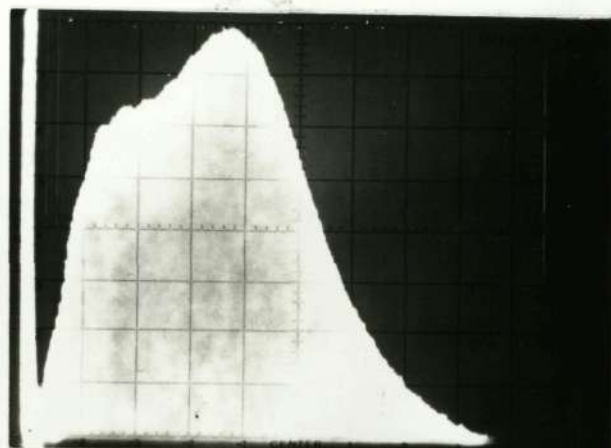
27Ω



0.2 μs/cm  
Transducer: Broadband VIP-10-1/2 C.  
Lower trace gate shows region whose  
spectrum appears at right

12Ω

FREQUENCY DOMAIN













Spectra obtained with HP  
spectrum analyzer, linear  
scale, 2 MHz/cm.

Fig. D-5. Effect of parallel resistance  $R_p$  on echo shape and spectral bandwidth.

## APPENDIX E: THREE-CHANNEL SIGNAL PROCESSOR

General layout designed so location of controls indicates function. Mechanical vernier (screwdriver) adjustments are designed to avoid accidental misadjustment. Features include:

GATES:	Three (3) channels, denoted A, B and C: These gates may monitor, for example, coupling, flaw and rear face echo; also useful for reflection coefficient and attenuation measurement by buffer rod ABC method; gates are virtually stepless, for spectrum analysis with minimal transient interference. Gated intervals are indicated by pedestals. GATE COMPLEMENT mode blanks 7000-series oscilloscope display except for gated parts of trace. GATE POSITION in each channel adjustable in three ranges: up to 1, 10, 100 $\mu$ s. Gate position is timed relative to either SYNC pulse or ECHO. This time reference is independently selectable for each channel - A, B and C. For the "A" channel, the ECHO reference means that the delay is relative to the main bang which typically follows the SYNC pulse by a short controllable delay. Gate WIDTH is adjustable between 1 and 10 $\mu$ s.
OUTPUT SIGNAL:	Available per channel individually (for spectrum analysis or other measurements) or with all 3 channels in common at OUTPUT SIGNALS connector.
RECORDER OUTPUT:	Three (3) position switch selects most positive (+), most negative (-) or largest (MAX) echo in gated time slot. 1% accuracy relative to INPUT SIGNAL at 1 kHz prf, for echoes longer than peak detector acquisition time. Bipolar output for determining sign of reflection coefficient, specimen impedance, etc.
COMPARE MAGNITUDE:	Two-position COMPARE MAGNITUDE switch, in conjunction with bipolar LEVEL control and EVENT indicators, controls ALARM indication and output corresponding to any one of four combinations of echo magnitude and bipolar level magnitude:

LEVEL 	COMPARE <  >	ALARM IF	Examples	
			ALARM	No ALARM
+	>	echo  >  + level		
+	<	echo  <  + level		
-	<	echo  <  - level		
-	>	echo  >  - level		



EVENT: Logic output to event recorder, corresponding to alarm light.

LEVEL: Pedestal display indicates sign and magnitude of this bipolar control, corresponding to + or - rotation of control knob. That is, besides use with COMPARE and EVENT functions, it controls polarity and magnitude of OUTPUT GATES which are available for oscilloscope display.

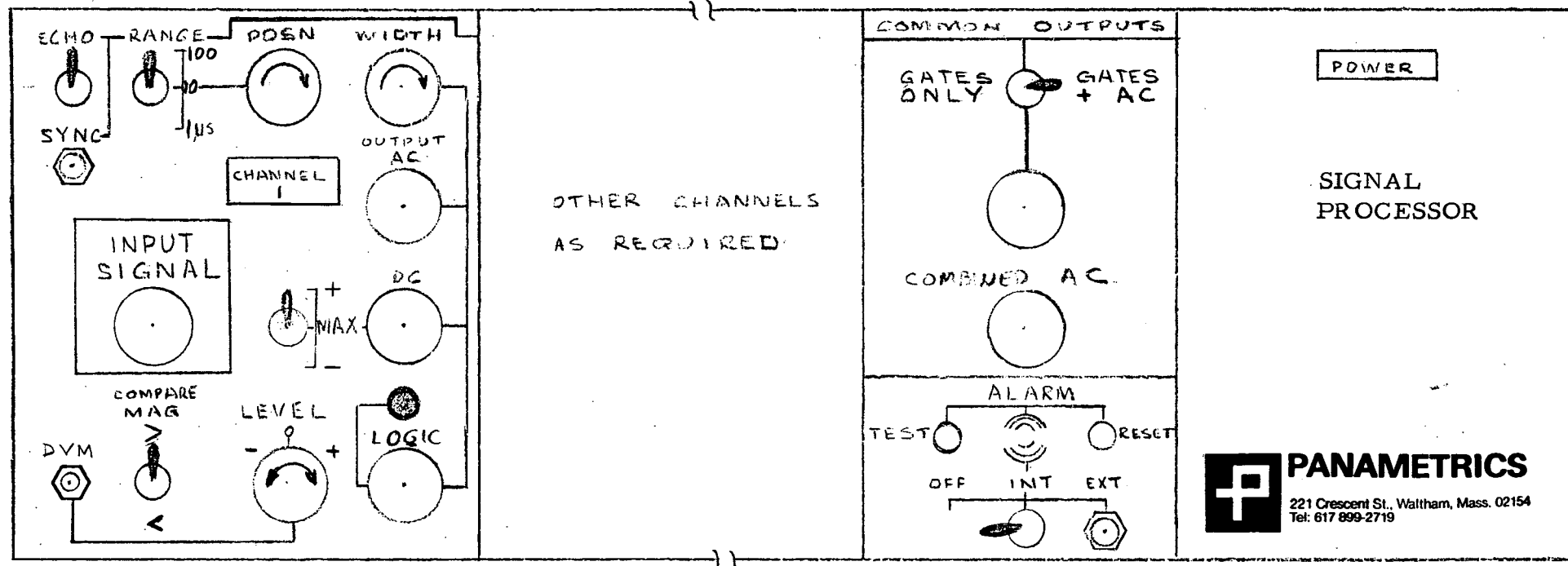
ALTERNATING  
GATES/SIGNALS: Sequential display requiring only one channel of oscilloscope.

ALARM: Includes TEST, RESET, INT audible alarm, and EXT logic level for EVENT occurring in any 1 or more gated time slots.

SIZE: 14 x 21 x 37 cm.

WEIGHT: Less than 10 kg.

POWER: 110/220V, 50/60 Hz; fused.



3.5

19"

Fig. E1. Schematic layout of Three-Channel Signal Processor.

Fig. E2.

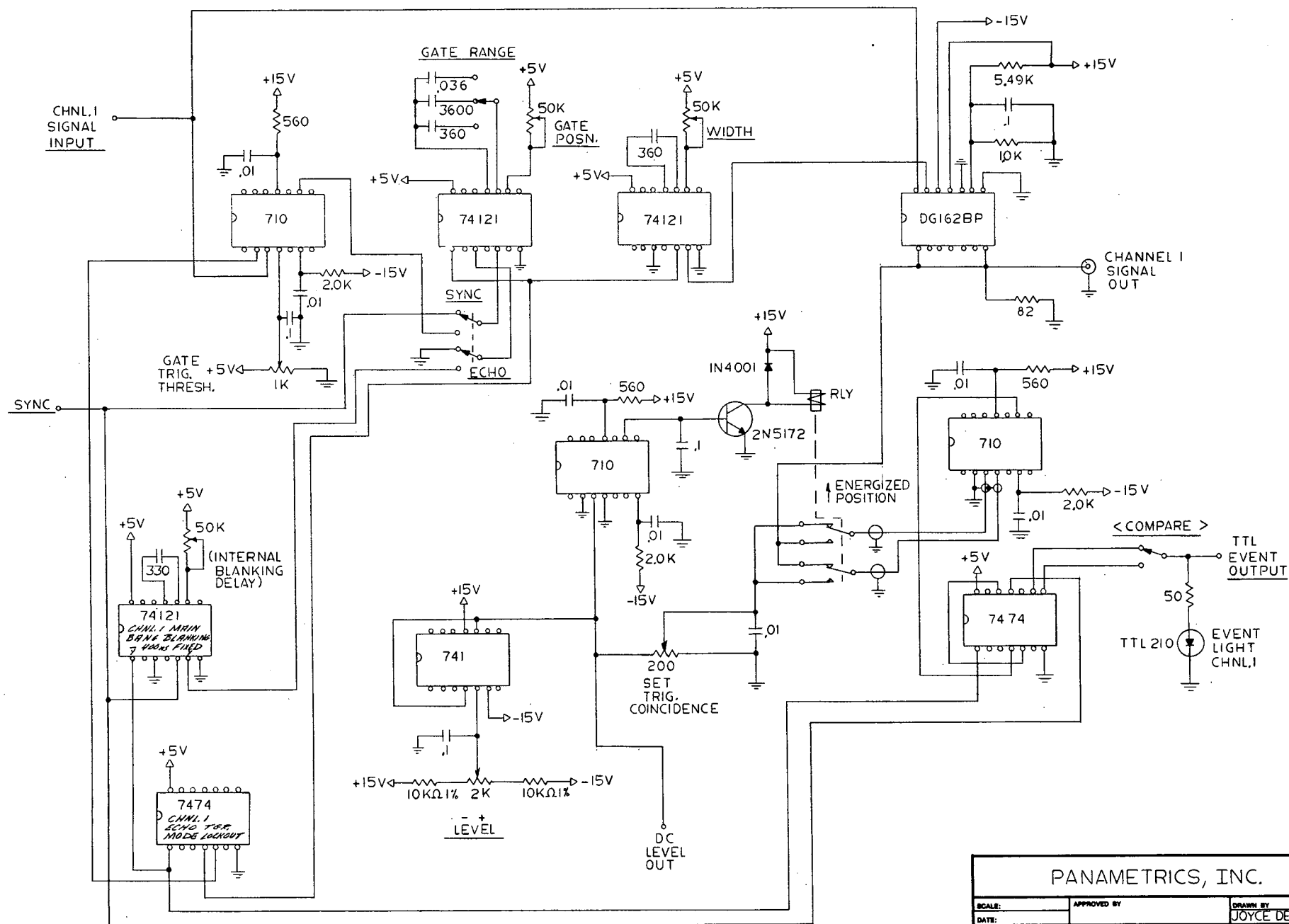
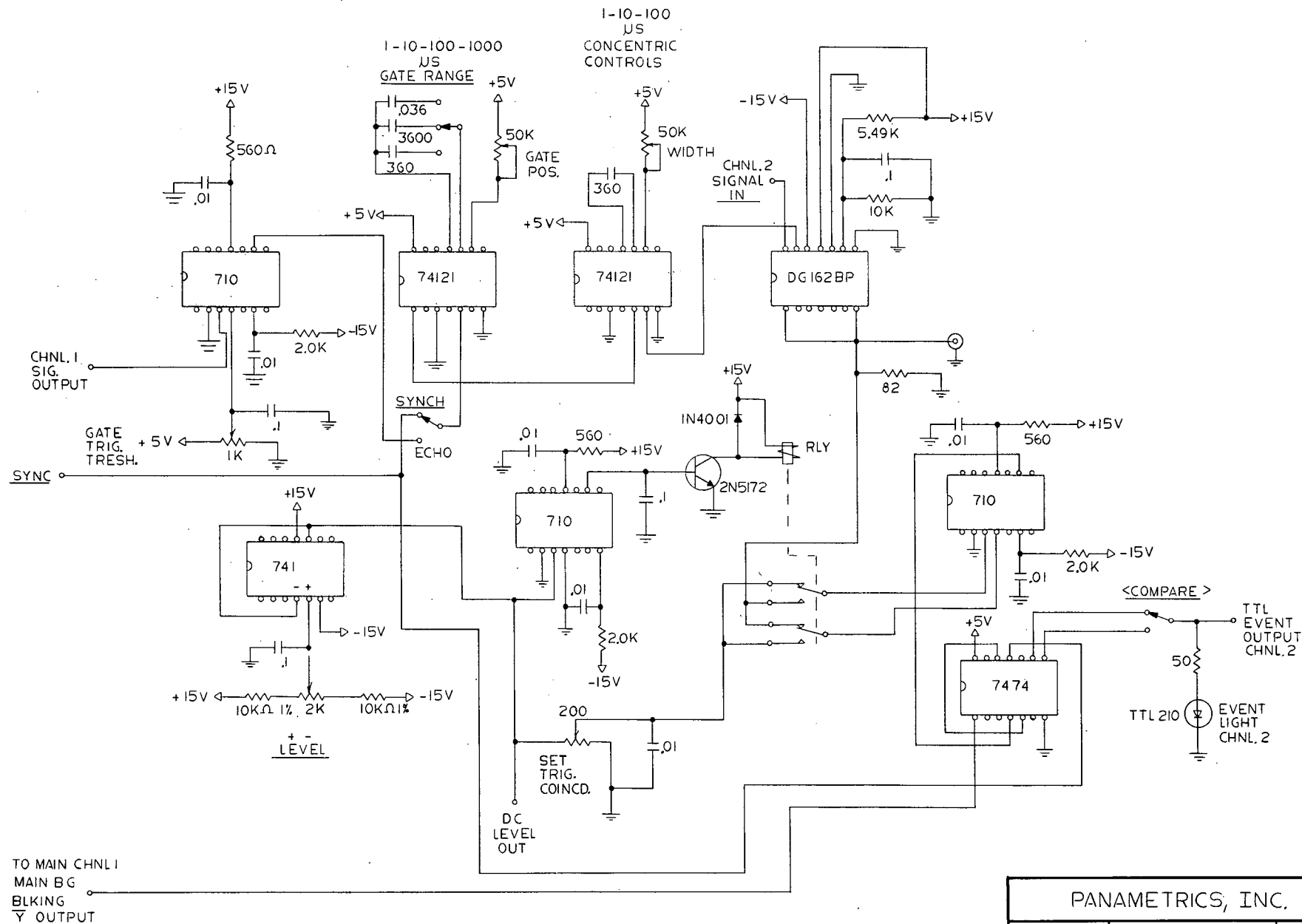


Fig. E3.

PANAMETRICS, INC.		
SCALE:	APPROVED BY	DRAWN BY
DATE:		JOYCE DESIGN
CHANNEL 1		
		DRAWING NUMBER



PANAMETRICS, INC.

SCALE:	APPROVED BY	DRAWN BY
DATE:		JOYCE DESIGN
CHANNEL 2		
		DRAWING NUMBER

Fig. E4.

[illegible]

SCALE:	APPROVED BY	DRAWN BY
DATE:		JOYCE DESIGN
CHANNEL 3		
		DRAWING NUMBER

Fig. E5.

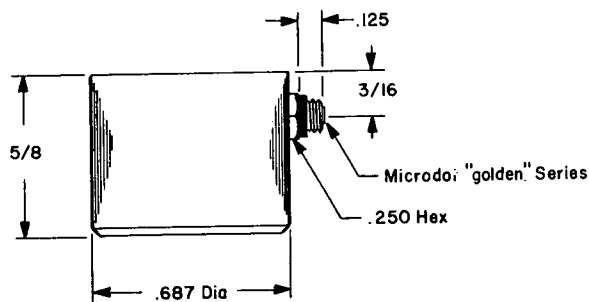
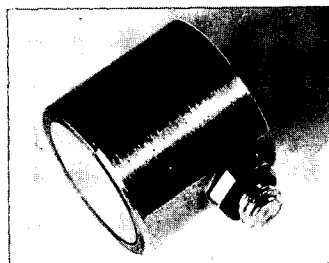
# APPENDIX F: BROADBAND TRANSDUCERS

# ULTRASONIC TRANSDUCERS

RESEARCH • TEST • INSPECT • MEASURE • EVALUATE • CONTROL

## VIP Series Video Inspection Panaprobe® Broadband Transducers

Specifications  
Model 5070 VIP-10-1/2 C Transducer  
(Style C for contact testing)



### Mechanical:

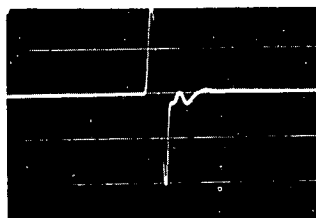
Case Material: Stainless steel, satin finish.

Wear Plate Material: Alumina, 99.5% pure, impervious, polished to better than 10 micro-inch rms.

Electrical Connector: Microdot "golden" series.

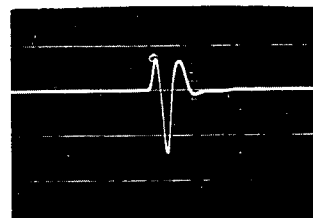
### Performance Characteristics:

Typical pulse-echo waveform reflected from fused silica test block at  $S_c^* \cong 1$ , commonly referred to as the  $y_0^+$  point (1" thick). Excitation pulse; -100V, 20 ns wide at half amplitude points. Cable; RG-174/U, 1ft long.



Load Resistance = 50Ω

0.2V/cm  
0.2μs/cm



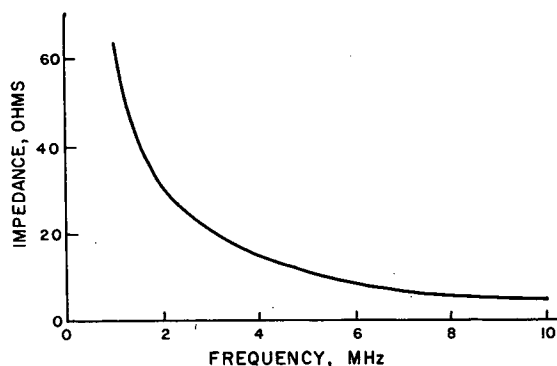
Load Resistance = 10Ω

The exact waveform and pulse spectrum obtained are dependent on a number of factors related to the instrumentation, the excitation pulse width, the material through which the pulse is propagated, and the length of the sound travel path. With a high impedance termination, i.e., load resistance of greater than 35 ohms, single cycle waveforms can be obtained. If the load resistance is lowered to 10 ohms, 1-1/2 cycles are normally observed. Both statements apply when the pulse is transmitted through a low attenuation material and travels a total distance equivalent to one  $S_c$  parameter.

Damping Factor: 2 or 3, depending on load resistance. Damping factor is defined as the number of half cycles equal to or greater than half the amplitude of the first half cycle in the rf pulse.

Loop Sensitivity: -43 dB typical, -50 dB min. Measured as the ratio of the amplitude of a 20 ns wide (at the half amplitude points) excitation pulse, measured across the transducer, to the peak-to-peak amplitude of the back reflection from a 1" thick silica test block, with a load resistance of 200 ohms.

Capacitance: 2500 pf typical.



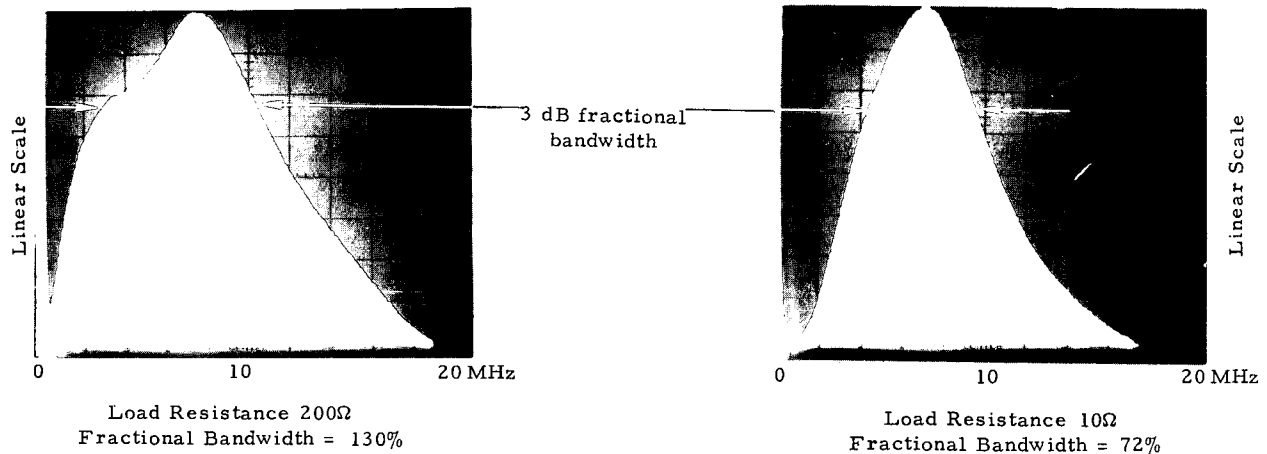
Variation of the magnitude of transducer electrical impedance with frequency.

\*  $S_c = \frac{\lambda_c Z}{2a}$  where  $\lambda_c$  is the wavelength of sound in the transmitting material at the center frequency,  $Z$  is the distance of pulse travel, and  $a$  is the transducer radius.



**PANAMETRICS** 221 Crescent St., Waltham, Mass. 02154 • Tel: 617 899-2719  
Subsidiary of Esterline Corporation F-1

Typical Spectrum of back echo from 1" thick fused silica test block,  $S_c \cong 1$ .



Fractional Bandwidth: 100% typical, 80% min. as measured at -3 dB of the pulse spectrum (B. W. =  $\frac{\Delta f \text{ at } 3 \text{ dB}}{f_c}$ ). Pulse "center frequency"  $f_c \equiv$  midpoint of the -3 dB (half power) points. Load resistance, 50Ω.

Backing Noise: <-80 dB. Measured as the ratio of the amplitude of the first back echo from a 1" thick silica block to the maximum signal returned from the transducer backing.

Operating Temperature Range: 32 to 120F, 0 to 50C.

**Electrical:**

Recommended Pulser/Receiver Characteristics:

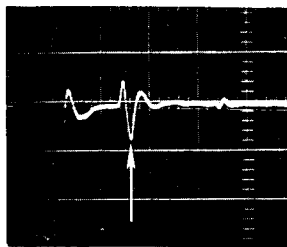
Pulse width:  $\leq 50$  ns measured at the half amplitude points.

$T_r$ :  $\leq 10$  ns.

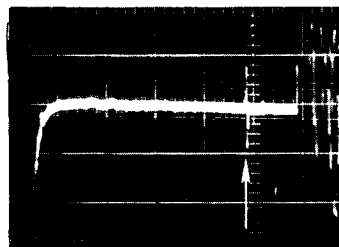
Maximum voltage: -100V guaranteed for a unidirectional voltage pulse of the above characteristics. Most transducers will withstand much higher voltage spikes but "punch-through" voltage is variable from unit to unit. The VIP-10-1/2 may also be driven with rf bursts over most of its usable bandwidth. In general, excitation voltages should be reduced for rf burst operation.

Typical Applications: Thickness gaging, high resolution flaw detection, flaw identification and/or characterization by spectrum analysis, measurement of frequency dependent attenuation effects by spectrum analysis. The VIP-10-1/2 can be utilized on a variety of measurements on both metallic and nonmetallic solids and liquids.

Documentation: Pulse waveform and pulse spectrum at the  $y_0^+$  of the center frequency, bandwidth and loop sensitivity are provided with each transducer at no charge.



ASTM 7075 Aluminum  
Test Block  
1/16" Dia FBH,  
1/8" Below Surface  
Contact Test  
5 mV/cm  
0.5  $\mu$ s/cm



ASTM 7075 Aluminum  
Test Block  
1/64" Dia FBH,  
3" Below Surface  
Contact Test  
200  $\mu$ V/cm  
5  $\mu$ s/cm

The above oscillograms demonstrate the resolution and sensitivity of the VIP-10-1/2C.

Additional Information: Technical Memorandum No. 6 entitled "Broadband Transducers: Radiation Field and Selected Applications," by E. P. Papadakis and K. A. Fowler, is available on request. Order ultrasonic reprint UR-90.

Other standard and special VIP series transducers are available from Panametrics. Call or write K. A. Fowler  
Specifications subject to change without notice.



**PANAMETRICS** 221 Crescent St., Waltham, Mass. 02154 • Tel: 617 899-2719  
Subsidiary of Esterline Corporation



## APPENDIX G: INSTRUCTION MANUAL FOR PULSER/RECEIVER 5051

### INTRODUCTION

The Pulser/Receiver 5051 is a prototype instrument designed for quantitative ultrasonic testing (Fig. 1). It was designed for use with broadband transducers operating in the 1 to 10 MHz frequency range, but it is not limited to these restrictions. It operates as a plug-in to any 7000-series Tektronix oscilloscope. It is normally plugged into the leftmost oscilloscope bay, but it can be plugged into any other bay too, to derive the necessary power. To operate with any oscilloscope not in the Tektronix 7000-series, a power supply would be required to provide the following dc power (Tektronix notation):


<u>5051 Pin Connection</u>	<u>Volts</u>
A9	LTS, +5
A14	LTS, COM
A12	GND
A18	+15
B12	GND
B18	-15
A19	+50
A8 (J1008)	+5

### GENERAL OPERATION

The following information is presented as a general guide. Depending on the particular application (measurement of flaws, thickness, velocity, attenuation, phase or time interval, or other special cases) a different procedure may be chosen or specified.

Let us assume the oscilloscope mainframe is a Tektronix R7704, turned on and operating properly. Let us further assume the bays contain, from left to right, these four engaged plug-ins: 5051, 7A12, 7B52, Accessory Bin. Reference to Fig. 1, or to the 5051 itself, will familiarize the operator with the nomenclature and position of the various front-panel pushbutton and toggle switches, unlabeled verniers, and connectors.

One may now normally\* operate the 5051 as follows:

1. Connect Microdot/BNC cable ( $\geq 1$  ft long) from 5051 SYNC to 7B52 MAIN TRIG IN.
2. Connect BNC/BNC cable ( $\leq 1$  ft long) from 5051 RCVR OUT to 7A12 CH 1.
3. Unlatch all 5051 lit pushbuttons, by pressing unlit adjacent pushbutton halfway in. Push in RCVR ATTN 0 dB.
4. Push 5051 CAL CW pushbutton, and the 1 or 10 MHz pushbutton, and one of the N $\sim$  pushbuttons, to check or adjust 7B52 at 1 or 0.1  $\mu$ s/div, respectively. Adjust SWEEP CAL vernier on 7B52 as required. Time base is now calibrated. Push in 1 MHz.
5. Push 5051 CAL  pushbutton. This internally injects into input of 5051 receiver, a group of 0.1V x 0.5 $\mu$ s rectangular pulses, with rise and fall times of about 20 ns. Adjust 5051 RCVR GAIN (unlabeled) vernier for gain of 10 by rotating vernier until 1V amplitude is measured at RCVR OUT. The receiver gain is now calibrated.
6. Observe rise and fall times  $t_r$  and  $t_f$  of the rectangular calibration pulses. The transition times should be about 25 ns. Calculate receiver bandwidth using the approximation:  $BW \approx 1/2 t_r$ . Example: if  $t_r = 25$  ns,  $BW \approx 20$  MHz. The 5051 contains no operator adjustments for bandwidth. If bandwidth is observed to be inadequate, consult factory (Panametrics).
7. Alternative calibration procedure: instead of steps 4, 5 and 6, one may utilize an independent signal source to calibrate time base, receiver gain and to check receiver bandwidth.
8. Having calibrated the 5051, we are now ready to operate it. Push OPER pushbutton.

\*In "normal" operation, the 3-position switch S1003 on board A10 is switched to NORMAL, not to one of the two OVERLAP positions. Also, the internal coupling capacitor switch S501 on board A5 is normally set to position 1, 2000 pf (max). See Fig. 2.

9. Select PULSE SHAPE by pushing spike shape S1 or S2, or radio frequency pulse burst shape RF. If RF is selected, also select frequency in MHz and number of cycles N~ as 2, 4, 8, 16 or 32.
10. Select appropriate transmitter termination in order to calibrate transmitter, after noting the following. The amplitude of the S1 or S2 main bang (initial spike) can be controlled up to 300V and 200V, respectively, by the transmitter spike step attenuator (0-10-20 dB) and spike vernier. The amplitude of the RF main bang can be controlled between 7 and 14V peak-to-peak by the RF vernier. Since the amplitude and shape of the main bang depend in part on the damping resistance (OHMS), the cable impedance and length, and on the transducer impedance (which in turn may vary with coupling conditions), one may sometimes prefer to not calibrate the transmitter until these factors have been defined. For example: damping OHMS = 100, cable impedance =  $50\Omega$ ; cable length = 4 ft (1.2 m); transducer impedance =  $-j 6\Omega$  ( $Z = -j/2\pi fC = -j/2\pi \cdot 10^7 \cdot 2500 \times 10^{-12}\Omega$  for Panametrics VIP-10-1/2 transducer at 10 MHz). However, the transmitter may be calibrated as follows, for a given cable/transducer/coupling situation, or for any other convenient termination to the transmitter BNC, such as open circuit,  $50\Omega$ , short-circuited cable, etc.
11. If only one transducer is to be used (pulse-echo), operate transducer toggle switch to center position. Otherwise operate toggle to left position and connect BNC tee to transmitter.
12. Select PRF: 100, 200, 500 or 1000 pulses per second.
13. Using 10X scope probe, connect probe tip to R or T/R connector, and measure main bang on 7A12 at 5V/div. (If 10X probe is not available, use 1X probe or coaxial cable but attenuate main bang by 20 dB.) Adjust 5051 step attenuator and vernier as required. The transmitter amplitude is now calibrated for the selected pulse shape.
14. Operate transducer 3-position toggle switch to left, center or right position. Left is for one transducer only (pulse-echo). Right is for electrically separate transmitter and receiver transducers. Center is seldom used; it is for connecting transmitter and receiver transducers in parallel electrically, or for calibration purposes (step 11).
15. Disconnect unnecessary connectors, cables, terminations or probe.

16. Proceed with test.
17. Typical 5051 settings are indicated in the "Illustrations" section of this manual.

#### SPECIAL OPERATION FOR EXTERNAL OVERLAP

This section describes the settings and procedure for measuring time interval by the pulse-echo-overlap method wherein the x-axis is driven by an externally-applied, variable-frequency continuous wave whose period is adjusted until it equals the interval in question.

1. Remove 5051 from R7704.\* Remove right side panel. Referring to Fig. 2 for switch notation and location, set S1001 at the HI position, set S1003 to position 2, and set S1002 to position 3 ( $\div 100$ ). These latter settings are done by snapping open the hinged transparent cover, rotating the slotted rotor to the desired position, and then closing the cover.
2. Replace right side panel. Install 5051 in R7704. Turn on R7704.
3. For first-time operation, use a VIP-5-1/2C transducer, ground 3" steel buffer at least 1" thick or 1" in diameter, and a steel specimen  $\sim 1/2$ " long by at least  $1/2$ " in other dimensions. A steel gage block is generally suitable for this specimen. Couple the three items together, using a clamp or other fixture to prevent relative motion during the measurement.
4. Connect cables (at least 4 ft long) from 5051 RCVR OUT to 7A12, CH 1, from 5051 SYNC to 7A12 CH 2, from T/R to the transducer, and from GR 1312 decade oscillator to 5051 EXT. Push OPER, S1, Xmtr ATTN = 10 dB, PRF EXT and MHz EXT. Push N = 2.
5. On 7A12, push TRIGGER SOURCE: CH 1, push CH 2 VOLTS/DIV:5, and DISPLAY MODE: ALT.
6. On 7B52, rotate TRIG LEVEL/SLOPE to about 4 o'clock position, push NORMAL, AC, INT, MAIN SWEEP. Operator should now see two traces. One is the echo train. The other is the SYNC output.
7. Observe the time  $t$  between selected echoes A and B, and measure it to  $\sim 1\%$  using the calibrated sweep.

\*Turn off R7704 when removing or installing 5051.

8. Set oscillator output to  $\sim 1V$ , and set its frequency  $f \approx 1/t$ , using 7D14 or other counter to measure  $f$ , or using timer to measure oscillator period. The frequency  $f$  should now be within about 1% of the correct value.
9. On 5051, advance N from 2 towards 32, until leading edge from the TR switch is as close as possible but left of echo A.
10. Adjust 5051 Sync Delay vernier until trailing edge closely follows B. The AB pair is now straddled. See Fig. 12.
11. Disconnect cable from 7A12 CH 2 and reconnect to R7704 Z-AXIS INPUT, HIGH SENSITIVITY (rear panel).
12. On 7B52, rotate TIME/DIV to full ccw AMPL position, MAIN TRIGGERING SOURCE to EXT  $\div 10$ , and connect oscillator output to MAIN TRIG IN.
13. Adjust oscillator  $f$  and 5051 Sync Delay and horizontal POSITION (R7704) until you observe overlap near center of display. Some adjustment of oscillator output and readjustment of  $f$  may be necessary. Record overlap frequency. Multiply path length by  $f$ , to calculate velocity:  

$$V = 2 L/t = 2 Lf.$$
14. For best results the echoes A and B should have similar shape, and be overlapped at corresponding points, such as the first zero crossing. In Fig. 12, for illustrative purposes, we show overlap of the central lobes of A and B. If narrow-band transducers are used, sound velocity may be measured at the transducer center frequency. Or one may use the 5051 pulse to trigger an rf pulse generator, for rf overlap measurements.
15. Repeat measurement procedure to determine reproducibility. Precision of up to about 1% of the interval between successive zero crossings is to be expected. For a 5 MHz pulse, this limit is about  $\pm 2$  ns. Compare  $V$  with data from independent methods.

#### SPECIAL OPERATION FOR INTERNAL OVERLAP

This section, similar to the previous section, relates to the pulse-echo-overlap method wherein the sweep is triggered several times at a rate equal to the external cw oscillator, to provide an overlap of two selected echoes.

1. Remove 5051 from R7704.\* Remove right side panel. Referring to Fig. 2, set S1001 at the HI position, S1003 to position 3 and S1002 to position 3 ( $\div 100$ ).
2. Replace right side panel. Install 5051 in R7704.
3. Same as step 3 in previous section.
4. On 5051 set S1, Xmtr ATTN: 10 dB, OHMS: 1000, PRF: 1000, N: 2, MHz: 1. Connect cable from 5051 SYNC to 7A12 CH 2, and from 5051 RCVR OUT to CH 1.
5. On 7A12, set DISPLAY MODE: CH 1, TRIGGER SOURCE: CH 1. Adjust to see echo train. Observe and measure  $t$  between A and B to about 1%.
6. On 7A12, change DISPLAY MODE to ALT. Adjust Sync Delay until CH 2 pulse pedestal train display straddles B.
7. On 5051, push EXT MHz and EXT PRF.
8. Adjust  $f \approx 1/t$ .
9. Advance N as close as possible to left of A.
10. Adjust Sync Delay and N for minimum number of pedestal pulses just prior to A and B. See Fig. 13.
11. Reconnect from 5051 SYNC to 7B52 MAIN TRIG IN. Set 7B52 TRIGGERING SOURCE to EXT. Adjust 7B52 LEVEL/SLOPE to about 10:30 position.
12. On 7A12 set for CH 1 display only.
13. Adjust 7B52 TIME/DIV to greater than 10 or 20 times the interval  $t$  between A and B.
14. Adjust oscillator for overlap. Set 7A12 VOLTS/DIV for sharpest pattern. Center the display as required. Record overlap frequency. (See steps 14, 15 of previous section.)

---

\*Turn off R7704 when removing or installing 5051.

## CIRCUIT DESCRIPTION

This section of the manual describes the circuitry used in the Model 5051 Pulser/Receiver. The description begins with a discussion of the instrument using block diagrams. Then, each circuit is described in detail using block diagrams to show the interconnections between stages in each major circuit and the relationship of the front panel controls to the individual stages. Complete schematics of each circuit are given. One may refer to these schematics throughout the following circuit description for electrical values and relationships.

### Assembly and Component Numbers

The Pulser/Receiver is composed of separate assemblies as follows:

A1	Completed Unit
A2	Receiver
A3	Receiver Attenuator Switch
A4	Crystal Oscillators
A5	Spike Generator
A6	Spike Generator Attenuator Switch
A7	Damping Switch
A8/A10	28 Volt Regulator
A9	RF Burst Generator
A10	Interconnecting Plane and Logic
A11	Shape Switch
A12	Calibrate/Operate Switch
A13	Burst Length Switch
A14	PRF Switch
A15	MHz Switch

It should be noted that A8/A10 is not a separate assembly but part of the interconnecting plane and logic. Each assembly has its own material list and its parts are numbered accordingly. For example, a resistor appearing on assembly A15 would be numbered R1501. Assemblies A2 through A15 are part of assembly A1.

### Block Diagram

The following discussion is provided to aid in understanding the overall concept of the Model 5051 Pulser/Receiver before the individual circuits are discussed in detail. All interconnections occurring in the

Pulser/Receiver are indicated on the block diagram. Arrows are used to indicate the direction of signal flow and a variety of symbols are used to indicate the type of connection made. These symbols are called out in the Note section of the block diagram. All controls appearing on the block diagram are labeled by surrounding the title of the control with a rectangle. The location of these controls is also called out. The Pulser/Receiver can be subdivided into the following categories:

- Eight front panel pushbutton switches
- DC to DC Converter (PS101)
- Spike Generator (A5)
- Burst Generator (A9)
- Crystal Oscillators (A4)
- Receiver (A2)
- An Interconnecting Plane and Logic (A10)

The eight panel switches provide most of the controls necessary to operate the Pulser/Receiver. The power supply PS101 is a 500V dc to dc converter. This supplies the necessary power to operate the spike generator. The spike generator can provide up to 300V of broadband excitation for driving ultrasonic transducers. The rf burst generator provides a burst of rf having at least 10V peak-to-peak amplitude and containing a selectable number of rf cycles and is used for narrowband excitation of transducers. The four crystal oscillators provide sine wave excitation at 1, 2, 5 and 10 MHz. This excitation is used in driving the logic and also in producing the rf burst. The receiver is blanked during the main bang and for a controllable interval thereafter. It amplifies the received echoes by a factor of 10.

#### Detailed Circuit Description

Spike Generator A5. The 50 volts supplied by the oscilloscope mainframe is regulated by the 28V regulator A8/A10. The relay K801 connects this regulated voltage to the input of the dc to dc converter PS101. The output of the converter (500V dc) is supplied to pin J505 on the spike generator assembly.

Integrated circuit U501 and transistors Q507 and Q508 form a high voltage regulator which supplies voltage to the spike generator.

The spike attenuator switch A6 sets the output voltage of this regulator at 0, 10 and 20 dB below 500V dc. Calibration of this switch is adjusted by front panel control R602. Transistors Q505 and Q506



form a constant current source which is used in charging one of the selected coupling capacitors C501 through C505. SCR's Q501 through Q504, when triggered by the spike gate appearing at J503, discharge the selected coupling capacitor into the transducer through CR501. Relays K501 and K502 are used to short out the unrequired SCR's when the spike attenuator switch is in the -10 dB or -20 dB positions.

Crystal Oscillators (A4). Assembly A4 contains four Pierce crystal-controlled oscillators operating at 1, 2, 5 and 10 MHz. The proper oscillator is chosen by applying 15V dc to this oscillator through switch A15. The crystal oscillator output is coupled through assembly A10 to the rf burst generator assembly A9.

RF Burst Generator (A9). The crystal oscillator output is coupled through J906 to emitter follower Q908. The output of this emitter follower is connected through relay K901 to the input of integrated circuit U901. The emitter follower Q908 buffers the crystal oscillator output and feeds this signal to the logic located on A10. This signal is also used for sweep calibration by feeding it through J902 to the calibrate/operate switch and to the receiver.

U901 functions as a gated amplifier and produces a 3V peak-to-peak rf burst containing 2, 4, 8, 16 or 32 cycles of rf. The gating signal for this amplifier is derived from transistors Q910 and Q911. The burst output is peak detected on assembly A11 and fed to the input of Q912 at J904. This signal is then fed to Q911 and serves as an AGC for amplifier U901.

Transistors Q907, Q906, Q905, Q904 and Q911 form a buffered amplifier having a gain of approximately 4.8. The output of this amplifier is fed to the input of complementary emitter follower Q901 and Q902. This complementary emitter follower provides the low impedance necessary to drive the transducer to approximately 10V peak-to-peak.

L903 and its associated components provide short circuit protection for the complementary emitter follower transistors Q901 and Q902.

Receiver (A2). The receiver input is protected from overload by CR208 and CR 209, CR204 and CR205. Q211 and its associated circuitry comprise an electronic transmit/receive (TR) switch which protects the receiver input from damage caused by the large excitation voltages provided by the transducer driving circuitry. Transistors Q208, Q209 and Q210 convert the logic level TR gate drive signals to sufficient amplitude

and correct polarity for driving transistor Q211. This circuitry also provides compensation for switching transients introduced by the gate capacitance of Q211.

Transistors Q212, Q213 and Q214 form a high input impedance, low output impedance buffer amplifier having unity gain. This buffer amplifier is used to provide a low impedance drive for the receiver attenuator switch A3. The receiver attenuator switch is connected between J202 and J201 and provides attenuation in steps of 2 dB from 0 dB to 18 dB. Transistors Q204 through Q207 provide the receiver voltage gain. R211 is a front panel control located under the receiver attenuator switch and is used to adjust the receiver gain to a calibrated value. Internal operating bias for the receiver is adjusted by means of R212. The receiver output is buffered by transistors Q201, Q202 and Q203.

#### Interconnecting Plane and Logic (A10)

Input Signal Conditioning. The crystal oscillator signal is fed to A10 through P1001 from the crystal oscillator buffer located on A9. U1001 is a high speed comparator used to square the crystal oscillator sine wave signal. U1004 buffers the comparator output.

Overlap Frequency Dividers. Integrated circuits U1017 through U1020 each divide the conditioned input signal by 10. S1002 can be used to select any of the four outputs of these frequency dividers thus giving a signal having a repetition rate equal to the input signal divided by 1, 10, 100, 1000 or 10,000.

PRF Circuitry. Switches A14 and A15 and associated integrated circuits U1021, U1022 and U1023 make up the circuit used to generate the pulse repetition frequency. When the internal crystal oscillator is selected at 1 MHz, U1017 through U1019 divide this 1 MHz signal by  $10^3$ . U1021 divides this signal by 10, producing a signal having a PRF of 100 Hz at pin 10 of J1003. U1021 also has an output equal to  $1/5$  of the input frequency. This output is fed to pin 2 of J1003 thus providing a signal having a 200 Hz PRF. One section of dual flip-flop U1023 is used to divide the 1000 Hz clock signal by 2 thus producing a 500 Hz PRF.

When the internal crystal oscillator is set at 2 MHz, U1017 through U1019 again divide this signal by 1000 producing a 2000 Hz signal. This signal is further divided by flip-flop U1023 thus producing a 1000 Hz signal. The PRF is then generated in the same manner it was when the crystal oscillator was set at 1 MHz.

When the internal crystal oscillator is set at 5 MHz, U1022 is used to divide the resulting 5000 Hz signal by 5 thus producing again a 1000 Hz signal. The PRF is then generated again in the same manner that it was when the crystal oscillator was set at 1 MHz.

When the internal crystal oscillator is set at 10 MHz, U1022 is used as a divide by 10 circuit to divide the resulting 10,000 Hz signal by 10 so that a 1000 Hz signal is produced. Again, the PRF is produced in the same manner it was when the crystal oscillator was set at 1 MHz.

Cycle Counting Logic. For this discussion refer to the schematic, Fig. G1. The function of this circuitry is to generate a pulse having a length equal to the selected number of cycles of the clock frequency. A sync enable pulse presets flip-flop 1 of U1002 so that the Q output of this flip-flop is at a logical 1. This signal then allows the clock at pin 6 to set flip-flop 2 output to a logical 1 which is the burst gate signal at P1002. This signal in turn enables the flip-flops in U1005 through U1007 to count clock pulses. When the selected point on the burst length switch, A13, becomes a logical 1, U1003 provides a return to ground pulse which clears both flip-flops in U1002. This returns the burst length signal to ground at P1002, thus completing the cycle.

Sync Pulse Circuitry. U1008 is triggered by a signal derived from the PRF switch A14 and in turn triggers one-shot U1009 which produces a 100 ns wide pulse for synchronizing the oscilloscope sweep.

Spike Generator Sync Circuitry. One-shot U1010 produces a variable delay via S1001 and R101A for positioning the spike sync pulse which is produced by U1011. This pulse also provides the sync enable pulse for U1002 as discussed above.

TR Turn-On Circuit. U1009 provides a preset pulse to flip-flop 1 in U1025 thus turning on the TR switch 1 microsecond ahead of the main bang.

TR Turn-Off Circuit. U1013 provides a 300 ns delay after the end of the rf burst before triggering U1012. This resets flip-flop 1 in U1025, thus turning off the TR switch.

External Overlap Sweep Blanking. U1016 provides a variable width pulse of 5 to 100 microseconds for blanking the 'scope sweep during "external overlap." The leading edge of this pulse is ANDed in U1024 with the clock, producing a series of pulses which repeatedly triggers one-shot U1015. The first of this string of pulses presets flip-flop 2 in U1025 which through Q1001 intensifies the 'scope beam. When the trailing edge of the pulse produced by U1016 occurs, U1014 clears flip-flop 2 in U1025 so that the trace again is blanked through Q1001.

Square Wave CAL Circuit. The output of U1015 as described above is fed to a NAND gate in U1024 which shapes this pulse for the square wave calibration. This signal is fed to the receiver through J1002. The calibration pulse height can be set by adjusting R1013.

Internal Overlap Sync. The calibration pulses are fed to the "internal overlap" sync point on S1003 and are used to repeatedly trigger the 'scope sweep for triggered overlap measurements.



## APPENDIX H. INSTRUCTION MANUAL FOR RF POWER AMPLIFIER

### General

This section describes front panel control functions and general information necessary for operation of the RF Power Amplifier.

### Front Panel Controls and Connectors

Input Connector	Signal input connector for the Power Amplifier.
Plate/Screen Switch	Two-position switch used to select either the final amplifier plate or screen current to be read on the above meter.
Filament Switch and Indicator	Main power switch for Power Amplifier. Applies only filament power to final amplifier when plate switch is OFF.
Plate /Screen Current Meter	Reads plate (0 to 500 ma) or screen current (0 to 50 ma) depending upon position of Plate/Screen Switch.
Tuning	Main tuning control which resonates final amplifier plate tank at selected operating frequency.
Band Switch	Selects proper tank components for driver and final amplifier.
Time/Operate Switch	Selects 216 V dc or 368 V dc in the tune or operate position respectively for the screen of the final amplifier.
Plate Switch and Indicator	Applies full plate voltage and screen voltage to final amplifier.
Output Connector	Point at which transducer and cable are connected.

Receiver Connector	Protected output connector for connecting power amplifier output to a receiver.
RF Output Meter	Reads the peak to peak RF voltage at the output connector.
Plate Tank Coils	Plug-in tank coils for 1 & 2, 5 and 10 MHz.

### General Operating Instructions

The following procedure demonstrates the basic operation of the controls of the RF Power Amplifier at one selected frequency.

#### Preliminary Settings

1. Set the controls of the 5051 Pulser/Receiver as follows:

Xmtr ATTN	0 db
MHz	Transducer frequency (1, 2, 5 or 10)
N <sub>~</sub>	Desired number of rf cycles (e.g., 8)
PRF	1000
Calibrate/Operate	OPER
Pulse Shape	RF
T/R-R	Right-hand R position

2. Connect 5051 sync output to 7B52 main trigger input and set the 7B52 controls as follows:

Trigger Level/Slope	10 o'clock
Main Triggering	Normal, AC, Ext
Display Mode	Main Sweep
Time/Div	5 $\mu$ s/div

3. Connect 5051 RCVR OUT to CH 1 input of 7A12, and set the 7A12 controls as follows:

Display Mode	CH 1
Trigger Source	CH 1

- |                |         |
|----------------|---------|
| Volts/Div      | 1 V/div |
| Input Coupling | AC      |
4. Connect the T/R output of the 5051 to the RF Power Amplifier INPUT and set the controls of the Power Amplifier as follows:
 

Plate/Grid Switch	Plate
Filament	OFF
Tuning	Transducer frequency
Band	Transducer frequency
Plate Tank Coil	Insert the correct tank coil for the frequency being used into the socket located under the door in the right front corner of the Power Amplifier top cover.
Tune/Operate Switch	Tune
Plate Switch	OFF
  5. Connect the Power Amplifier output to the transducer selected.
  6. Connect the Receiver connector on the Power Amplifier to the R input on the 5051.

#### Tuning and Operation

1. Turn on the R7704 and the Power Amplifier filaments.
2. Set the 5051 RF amplitude vernier to minimum output (full ccw).
3. After a 30 second warm-up turn the Power Amplifier Plate Switch to On and adjust the tuning control for maximum reading on the RF Output Meter. Turn the Plate Switch to OFF.
4. Set the Tune/Operate Switch on the Power Amplifier to Operate and set the Plate Switch back to ON. At this point the RF Output meter should be reading less than 100 V pp (full scale) and the Power Amplifier plate current should be about 100 ma dc.
5. The RF output may now be increased to 100 V pp by increasing the output of the 5051. (Rotate the RF Amplitude vernier clockwise). In some cases, when a length of cable appears between the transducer and the Power Amplifier Output, it will not be possible produce a full scale reading on the Output Meter. This is due to the low input impedance to the cable caused by the transformation of the transducer's capacitance from the receiving end to the sending end of the cable.



6. Echos and an attenuated main bang should now be visible on the oscilloscope.

## Circuit Description

### Introduction

This section describes the circuitry used in the RF Power Amplifier. The schematic diagram will assist one in following the discussion.

### General Description

Power Supply. Switch S1 applies power to the filament transformer T2, the fan, the grid bias transformer T3 and the driver amplifier plate and screen transformer T6. A 30 second filament warm-up delay is provided by K2 so that the final amplifier filaments (V1 & V2) have sufficient warm-up time before plate voltage can be applied.

Plate and screen voltage for the final amplifier are produced by T1, and cannot be applied until the 30 second warm-up delay has elapsed. The Tune/Operate switch S2 and K1 are connected so that the plate power switch CB cannot apply plate and screen power unless S2 is in the Tune position.

Regulator tubes V3, V4 and V5 provide 368 volts of regulated screen voltage for the final amplifier, V1 and V2.

Driver Amplifier. The input signal is fed to the driver amplifier V6 from J1 through a series resonant grid circuit. The plate tank for the amplifier is a split type so that it produces properly phased grid driving voltage for the final amplifier, V1 and V2.

Final Amplifier. The final amplifier V1 and V2 is arranged in the push-pull configuration to minimize distortion of the amplified signal. Proper tank components are selected by S4 and the plug-in coils provided.

Output Meter Circuit. The voltage appearing at the output connector is peak-to-peak detected and displayed on the Output Meter with 100 V peak-to-peak being full scale.

Cable Effects. As discussed in Appendix C, the effect of cable length on the performance of the pulser-receiver in spike modes

S1 or S2 is to generally degrade the transmitter efficiency and receiver response above 10 MHz. For a general guideline, cables should be kept as short as possible, not over 10 feet in any instance, if consistent with the application.

For use in the rf burst mode, the same guideline is appropriate except at 10 MHz where the maximum length should be 3 feet to avoid extreme loss of efficiency.

The following points apply equally to use of cables for the rf burst mode with the Pulser/Receiver 5051 alone or with the RF Power Amplifier.

Table H1. Cable-Transducer Loads \*

FREQUENCY MHz	MAXIMUM TRANSDUCER CAPACITY pf	MAXIMUM 50Ω COAXIAL CABLE LENGTH	
		ft	m
1	1000	150	~ 50
2	1000	100	~ 30
5	1500	16	~ 5
10	2500	3	~ 1

These cable lengths are computed on the basis of limiting the minimum voltage transfer ratio of the cable transformer effect to unity. Lengths shorter than these will have a multiplication effect on the voltage at the transducer, reaching a maximum at a length of:

$$l = \frac{1.03 \times 10^8}{f} \tan^{-1} \frac{3.18 \times 10^{-3}}{f C} \text{ ft}$$

Optimum cable lengths are shown in the table below. The multiplication factor will depend on amplifier tuning but can range from unity to about 5.

\* Cable lengths are computed for cables having a speed of electromagnetic wave propagation equal to 66% of the free-space value.

Table H2. Optimum Cable Length

FREQUENCY	TRANSDUCER CAPACITANCE	OPTIMUM CABLE LENGTH	
		ft	m
1	500	146.4	~ 45.0
2	1000	52.0	15.8
5	1500	8.3	2.5
10	2500	1.3	0.4

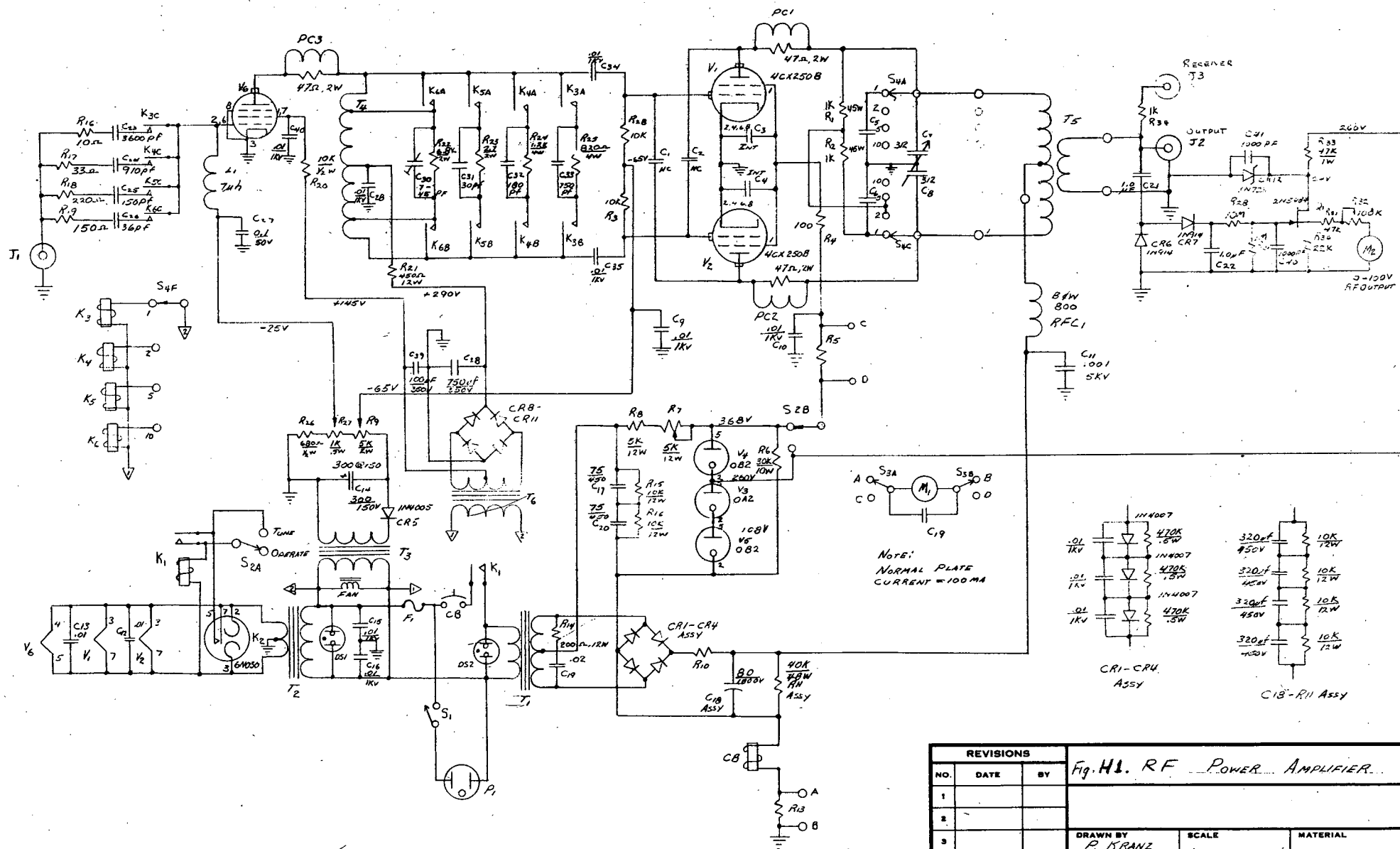


Fig. H1.

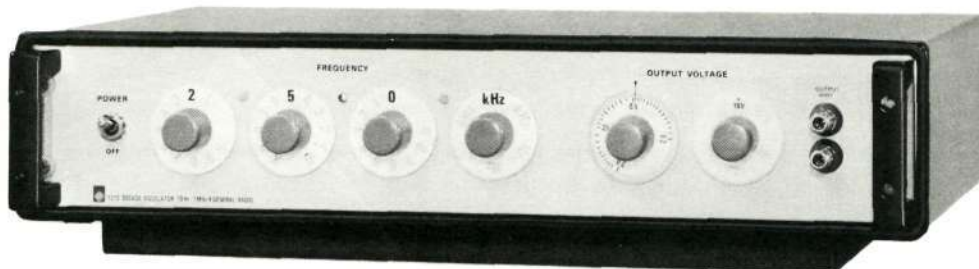
REVISIONS			Fig. H1. RF POWER AMPLIFIER		
NO.	DATE	BY			
1					
2					
3			DRAWN BY	SCALE	MATERIAL
4			CHK'D	DATE	DRAWING NO.
5			TRACED	APP'D	

Data Sheets on Tektronix  
R7704, 7A12, 7B52

Available: Tektronix Inc.  
P. O. Box 500  
Beaverton, Oregon 97005

## Type 1312 DECADE OSCILLATOR

- 10 Hz to 1 MHz
- 20-V output, 80-dB step attenuator
- low distortion and hum
- decade controls, in-line readout

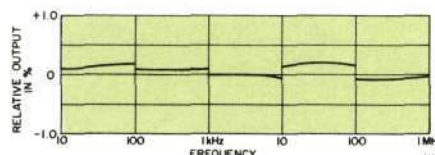
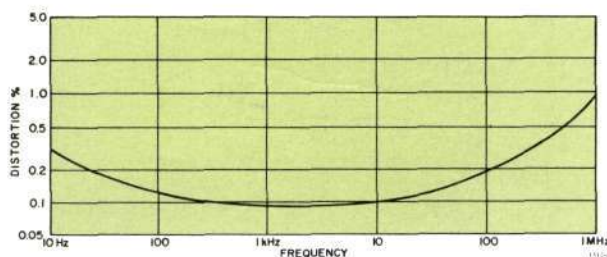


The 1312 permits frequency to be set fast, yet accurately, and with little chance of operator error. Thus it is the ideal oscillator for the many production and quality-control tests that demand laboratory performance and easy operation. Like a decade resistor or capacitor, the 1312 can be set to the desired frequency with two step decades and one continuously adjustable dial; selected frequency is displayed digitally in line, with decimal point and frequency units.

Although the 1312 is economical, it represents no performance compromises. The 20-volt output is held con-

stant to within  $\pm 2\%$ , without degrading the low distortion. For measurements of attenuation and gain, output level can be changed in precise increments with the precision 80-dB step attenuator, while a continuous control permits setting to any desired level. Output impedance of 600 ohms is maintained at all voltage levels, including the zero-volt setting of the attenuator provided for ease in locating sources of hum and noise in a measurement setup. The output of the 1312 is isolated from the chassis to reduce the effects of ground loops.

— See **GR Experimenter** for January 1968.



Typical low distortion (left) and uniform output level (above), shown as functions of frequency.

### specifications

#### FREQUENCY

**Range:** 10 Hz to 1 MHz in five decade ranges.

**Accuracy:**  $\pm 1\%$  of setting.

**Stability** (typical at 1 kHz): Warmup drift, 0.1%. After warmup: 0.001% short term (10 min), 0.005% long term (12 h). Resettable within 0.005%.

**Control:** Step control of two most significant digits, continuously adjustable third digit with detented zero position. In-line readout with positioned decimal point and frequency units. Most significant digit 1 through 10, second digit 0 through 9 with uncalibrated X for 10, third digit 0 through 9.

**Synchronization:** Frequency can be locked to external signal. Lock range  $\pm 3\%$  per volt rms input up to 5 V. Frequency controls function as phase adjustment.

#### OUTPUT

**Voltage:**  $> 20$  V open circuit.

**Power:**  $> 160$  mW into 600  $\Omega$ .

**Impedance:** 600  $\Omega$ . Isolated from chassis by 10  $\Omega$  across 0.1  $\mu$ F.

**Attenuation:** Continuously adjustable attenuator with  $> 20$ -dB range, and 80-dB step attenuator with 20 dB per step. Intermediate steps reduce output to zero while maintaining 600- $\Omega$  output impedance.

**Distortion:**  $< 0.25\%$ , 50 Hz to 50 kHz with any linear load. Oscillator will drive a short circuit without clipping.

**Hum:**  $< 0.04\%$  of max output or 4  $\mu$ V, whichever is greater.

**Amplitude vs Frequency:**  $\pm 2\%$ , 10 Hz to 100 kHz with  $\geq 600$ - $\Omega$  load;  $\pm 2\%$ , 100 kHz to 1 MHz with  $\leq 600$ - $\Omega$  load.

**Synchronization:** Constant-amplitude (0.8-V) high-impedance (27-k $\Omega$ ) output to drive counter or oscilloscope.

#### GENERAL

**Power Required:** 100 to 125, 200 to 250 V, 50 to 400 Hz, 13 W.

**Terminals:** Front-panel output, GR 938 Binding Posts; rear-panel output, female BNC connector. Sync, rear-panel, female BNC.

**Accessories Supplied:** Power cord.

**Accessories Available:** 776-A Patch Cord (BNC to shielded double plug).

**Mounting:** Rack-bench cabinet.

**Dimensions** (width x height x depth): Bench, 19 x 3 $\frac{7}{8}$  x 11 in. (485 x 99 x 330 mm); rack, 19 x 3 $\frac{1}{2}$  x 8 $\frac{7}{8}$  in. (485 x 89 x 225 mm).

**Weight:** Net, 13 $\frac{1}{4}$  lb (6.5 kg); shipping, 17 lb (8 kg).

Catalog Number	Description
1312-9700	1312 Decade Oscillator Bench Model
1312-9701	Rack Model